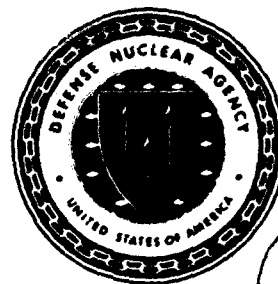




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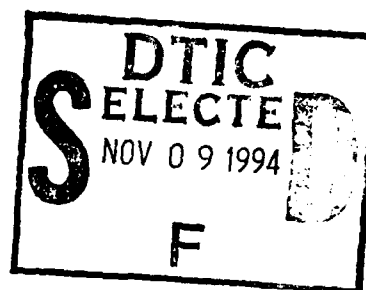


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DNA-TR-94-22

Reentry Vehicle On-Site Inspection Technology Study

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2800 Powder Mill Road
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November 1994

Technical Report

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13. ABSTRACT (Maximum 200 words) A study group was tasked to develop possible reentry vehicle on-site inspection (RVOSI) scenarios and to recommend research into technologies that could address these scenarios. The task was accomplished by identifying RVOSI technology candidates and evaluating their advantages or disadvantages to comparison to the visual protocol for RVOSI prescribed by the Strategic Arms Reduction Treaty (START) on the Reduction and Limitation of Strategic Offensive Arms. RVOIS technologies were evaluated with regard to inspection confidence, cost, intrusiveness, operational impact, and inspector burden. The RVOSI Technology Study identified no technology that readily solves the problems associated with START-prescribed visual inspection protocols. Recommendations for (1) further research in analytic modeling, (2) experimental studies to support this analytic work, and (3) data processing resulted from this study. Technology development for RVOIS appears to be primarily of interest if the technology provides enhanced confidence or additional inspection capability over visual inspections.				
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SUMMARY

A visual protocol for Reentry Vehicle On-Site Inspections (RVOSIs) is prescribed by the Strategic Arms Reduction Treaty (START) on the Reduction and Limitation of Strategic Offensive Arms as the method to verify that missiles carry no more reentry vehicles than the number of attributed warheads. In developing goals for research and development of treaty verification technologies, the Defense Nuclear Agency (DNA) commissioned this study to investigate technology solutions for RVOSIs as alternatives to the visual inspection protocol. The study was also to address the applicability of RVOSI technologies to potential future arms control issues related to assuring limitations on the number of warheads a missile may carry. Technologies were evaluated for their ability to satisfy the requirements of START, as well as new requirements stimulated by the START II agreement.

The task of this study group was to develop and evaluate possible RVOSI scenarios and to make recommendations for research and technology implementation. We identified RVOSI technology candidates and evaluated their advantages or disadvantages compared to the visual protocol, with regard to inspection confidence, cost, intrusiveness, operational impact, and inspector burden. Comparisons of the technologies that we evaluated also helped us determine whether each technology met a number of potential RVOSI objectives for specific types of missile systems. This process allowed us to evaluate how different inspection goals provide different motivations for developing a technology solution for the RVOSI task.

We found no clear indication that the use of a technology would eliminate intrusiveness or operational impact concerns associated with the visual inspection protocol, and technologies are unlikely to offer cost savings over visual inspections. The only potential advantages are that the use of technologies may offer additional inspection capabilities (such as identification of nuclear warheads rather than reentry vehicle (RV) shaped objects) and could enhance inspection confidence (as in the START II case, where a single warhead would be allowed on a missile designed to carry multiple warheads).

We found no technology to recommend for advanced development at this time. However, we identified a number of research issues to further assess how inspection confidence or capability could be enhanced by the use of a technology inspection. Our recommendations focus on passive radiation detection technologies, because of their ability to identify nuclear warheads as opposed to other missile system attributes. As deep cuts are made in arsenals and as missiles carry nuclear payloads much smaller than their designed throw weight would allow, we believe that the motivation for RVOSI will focus on nuclear warhead counting rather than RV attribution. Our recommendations cover five topics: analytic modeling studies, additional experimental studies, data processing issues, inspection system definition for advanced development, and confidence studies.

Our recommendations for analytic modeling study focus on radiation transport modeling studies in conjunction with all passive radiation detection techniques. We found it difficult to evaluate the confidence that can be placed in various technologies when they are applied to Russian configurations. Monte Carlo modeling efforts could determine tradeoffs between neutron and gamma-ray

detection methods, assess Russian configurations, and support spoofing scenarios. This type of calculation will be invaluable to DNA in developing their RVOSI technology investment strategy. Monte Carlo simulations of radiation transport in representative missile systems are our highest priority recommendation for immediate DNA investment.

Additional experimental work may be required in support of the calculational effort. We particularly recognize that at this time, the Minuteman III (MMIII) missile system still exists in a three-RV configuration—a “MIRV” (multiple independently targetable reentry vehicle)—but is in the process of being de-MIRVed to a one-RV configuration. Since we view the former configuration as more representative of future U.S. and Russian MIRVed submarine-launched ballistic missiles (SLBMs) under START II than the Peacekeeper configuration previously explored, we recommend that a set of tests similar to the Department of Energy (DOE) sponsored tests against the Peacekeeper be conducted against the MMIII configuration.

Data processing research was motivated by two assumptions we made in the decision tree process: (1) that intrusiveness caused by the use of technologies could be adequately reduced through data processing and (2) that an actual count of RV/warheads could be converted to a “not more than X” readout. We understood in making these assumptions that several barriers, both technical and political, would have to be overcome in order for this assumption to be fully realized. Consequently, we encourage DNA to invest in developing and proving—and therefore building confidence in—concepts that allow this kind of processing.

As we studied technologies, we found that our uncertainty of inspection system requirements often prohibited us from making adequate evaluations. Before any system is further developed, policy decisions must be made that further define the engineering details of many systems, and that may eliminate others. Technical evaluation of the techniques studied can identify tradeoffs between technologies, but the team felt unqualified to eliminate technologies because of unacceptable inspector burden, missile access restrictions, or changes in arsenals as arms reductions proceed.

Although confidence in the ability of a technology to complete an inspection was our most important evaluation factor, we found that no technology had been tested adequately for us to make a quantitative evaluation of reliability or spoof resistance. Enough data have been collected by some of the passive radiation-detection techniques that some assessment can be made, but any technology that is further developed will require statistical analysis of the potential for false positive results, serious spoofing (Red-teaming) studies, and proof of the technology against similar Russian systems.

The RVOSI Technology Study identified no technology that readily solves the problems associated with START-prescribed visual inspection protocols. Any commitment to hardware development should be preceded by at least modeling studies of the type discussed above. Technology solutions for the RVOSI task can be reevaluated in the future if other technologies are developed that introduce new capabilities. Technology development for RVOSI appears to be primarily of interest if the technology provides enhanced confidence or additional capability over visual inspections, particularly if it becomes desirable to determine the number of nuclear warheads on board a missile.

PREFACE

The Reentry Vehicle On-Site Inspection (RVOSI) Technology Study Team would like to thank our DNA sponsors, LCDR Randy Johnston, Bill Moon, and LTC Benard Simelton for their support throughout the study. We would also like to thank all those who participated in RVOSI Technology Study Group meetings and provided us with information used to evaluate technologies for the RVOSI application.

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CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurements

MULTIPLY TO GET BY TO GET
TO GET BY DIVIDE

angstrom	$1.000\ 000 \times E -10$	meters (m)
atmosphere (normal)	$1.013\ 25 \times E +2$	kilo pascal (kPa)
bar	$1.000\ 000 \times E +2$	kilo pascal (kPa)
barn	$1.000\ 000 \times E -28$	meter ² (m ²)
British thermal unit (thermochemical)	$1.054\ 350 \times E +3$	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical)/cm ²	$4.184\ 000 \times E -2$	mega joule/m ² (MJ/m ²)
curie	$3.700\ 000 \times E +1$	*giga becquerel (GBq)
degree (angle)	$1.745\ 329 \times E -2$	radian (rad)
degree Fahrenheit	$T_K = (T^{\circ}F + 459.67)/1.8$	degree kelvin (K)
electron volt	$1.602\ 19 \times E -19$	joule (J)
erg	$1.000\ 000 \times E -7$	joule (J)
erg/second	$1.000\ 000 \times E -7$	watt (W)
foot	$3.048\ 000 \times E -1$	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	$3.785\ 412 \times E -3$	meter ³ (m ³)
inch	$2.540\ 000 \times E -2$	meter (m)
jerk	$1.000\ 000 \times E +9$	joule (J)
joule/kilogram (J/kg) (radiation dose absorbed)	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	$4.448\ 222 \times E +3$	newton (N)
kip/inch ² (ksi)	$6.894\ 757 \times E +3$	kilo pascal (kPa)
ktap		newton-second/m ²
	$1.000\ 000 \times E +2$	(N-s/m ²)
micron	$1.000\ 000 \times E -6$	meter (m)
mil	$2.540\ 000 \times E -5$	meter (m)
mile (international)	$1.609\ 344 \times E +3$	meter (m)
ounce	$2.834\ 952 \times E -2$	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	$1.129\ 848 \times E -1$	newton-meter (N · m)
pound-force/inch	$1.751\ 268 \times E +2$	newton-meter (N/m)
pound-force/foot ²	$4.788\ 026 \times E -2$	kilo pascal (kPa)
pound-force/inch ² (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	$4.535\ 924 \times E -1$	kilogram (kg)
pound-mass-foot ² (moment of inertia)	$4.214\ 011 \times E -2$	kilogram-meter ² (kg · m ²)
pound-mass-foot ³	$1.601\ 846 \times E +1$	kilogram/meter ³ (kg/m ³)
rad (radiation dose absorbed)	$1.000\ 000 \times E -2$	**Gray (Gy)
roentgen		coulomb/kilogram (C/kg)
	$2.579\ 760 \times E -4$	
shake	$1.000\ 000 \times E -8$	second (s)
slug	$1.459\ 390 \times E +1$	kilogram (kg)
torr (mm Hg, 0°C)	$1.333\ 22 \times E -1$	kilo pascal (kPa)

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.

**The Gray (Gy) is the SI unit of absorbed radiation.

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SECTION 1 INTRODUCTION

The Defense Nuclear Agency (DNA) is tasked, within the Department of Defense, to conduct research, development, test, and evaluation programs for technology issues associated with arms control and treaty verification. Reentry vehicle on-site inspection (RVOSI) has been identified as a treaty verification procedure that technology solutions could potentially enhance. In April 1992, DNA commissioned this study to help define a set of design guidelines for selecting RVOSI technologies for development and to recommend research and development goals for the DNA RVOSI technology program.

The START Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms, signed in Moscow, on 31 July 1991, allows for visual inspections to confirm that missiles covered by the treaty carry no more reentry vehicles (RVs) than the number of attributed warheads. At the onset of this study, the visual inspection method was viewed as expensive, manpower intensive, intrusive, and operationally disruptive. Since this method of RVOSI has been negotiated and demonstrated, and protocols carefully documented, all other methods for completing RVOSI are compared to this baseline.

The task of this study group has been to develop and evaluate possible RVOSI scenarios and to make recommendations for research and technology implementation. We did not limit ourselves to the START criterion (that missiles carry no more RVs than the number of attributed warheads) in evaluating inspection methods. Technologies that have difficulty in meeting the "no more than" criterion without significant raw data masking may give an excellent actual count of RVs or of warheads. As arms reductions proceed, the detection of warheads, which are the actual items of concern for arms control, may become desirable. As the U.S. reaches future arms control agreements, it may be required to conduct more inspections, and inspection time may become the driving issue in negotiating future agreements. Finally, initiatives proposed by the President of the Russian Federation and the President of the United States in June 1992, and formalized in START II, emphasize de-MIRVing (removal of multiple independently targetable reentry vehicle) of land-based intercontinental ballistic missiles (ICBMs) and significant downloading of submarine-launched ballistic missiles (SLBMs).

The study task has evolved through three stages, described in this report. First, we identified and evaluated possible technologies for the RVOSI task against a set of evaluation factors that the team developed based on inputs from DNA, policy organizations such as the Joint staff, national security organizations such as the National Security Agency (NSA), and equipment users, including the on-site inspection agency (OSIA) and service representatives. Based on these technology evaluations, we developed a decision-tree process to rank the technologies as they apply to a number of inspection objectives. Finally, we reviewed the recommendations that resulted from the decision-tree process in light of the signing of START II in January 1993.

SECTION 2

RVOSI TECHNOLOGY CANDIDATES

The technologies we identified and studied for the RVOSI task were drawn from a large body of research conducted over many years. The identification of technologies drew heavily on the START Signature Exploitation Systems Analysis, conducted for DNA by System Planning Corporation [1], and on research conducted for the Department of Energy (DOE) Office of Arms Control and Non-proliferation [2]. Some technologies were developed specifically with the RV counting task in mind, and some technologies were developed for very different applications. This section describes the technologies we studied, as well as those we discussed and then eliminated from the study.

The technologies studied fall into four main categories based on the attribute of the missile system that is measured (that is, based on the signature): passive radiation detection, active radiation techniques, acoustic signatures, and gravity measurements. RV counting using an infrared (IR) signature was also proposed; however, due to the unavailability of past data and lack of present research interest in this technology, we omitted it from this study. The IR detection method raised significant concerns regarding spoofability and failure to produce a readily identifiable signature for the RVOSI application. Consequently, we feel that the omission of this technology primarily affects only the completeness of this report and not the outcome.

2.1 PASSIVE RADIATION DETECTION TECHNIQUES.

Of all the technologies studied, researchers have explored passive radiation detection technologies most fully. Most of the research in these technologies was conducted through DOE-sponsored programs. RVOSI using these technologies depends on the intrinsic radiation emission of nuclear warheads. Both gamma-ray and neutron radiation detection approaches have been proposed for the RVOSI application. Inspection systems that require circumferential access around the missile and those that make measurements end-on have been proposed and tested. The circumferential scanning methods measure the azimuthal variation in the gamma-ray or neutron radiation pattern at a fixed radius from the missile axis. This pattern indicates the number and placement of the warheads.

2.1.1 Neutron Detection.

Neutron detection schemes for RVOSI have been investigated by different research groups. A system developed by Los Alamos National Laboratory (LANL), passive neutron scanning (PNS), detects fast neutrons using a BC454 boron-loaded plastic scintillator originally developed for space-based neutron detectors. This detector, used independently of any other detection technique in a circumferential scanning mode, was tested at F. E. Warren Air Force Base (FEW AFB) against the Peacekeeper configuration [2].

An RVOSI method developed for the Air Force by SRS Technologies also detects fast neutrons. It uses four ^3He detectors, 1 in. in diameter and 8 in. long, enclosed in a specially fabricated housing for collimation. The housing is constructed of borated polyethylene on three sides, with a sandwich made of polyethylene and boron recessed in the collimation cavity on the fourth side. Neutrons are detected in combination with an x-ray fluorescence technique, which will be described in Section 2.6, *Active Radiation Techniques*. This technique has been tested against the Peacekeeper

configuration at FEW AFB in a circumferential scanning mode. SRS Technologies completed a design and proof-of-principle testing of this system for end-on inspection [3].

Pacific Northwest Laboratory has developed a directional neutron detector (DND) that was tested against the Peacekeeper configuration at FEW AFB in a circumferential scanning mode. The DND measures an azimuthal variation in the neutron radiation pattern at a fixed radius from the missile axis. The detector is a boron-loaded, plastic scintillator core, surrounded by an active shield of unloaded plastic scintillator. The DND distinguishes neutrons from gamma rays by strict timing requirements on three sequential signals, which result from neutron interactions in the detector [4].

The radiation pattern identification (RAPID) technique developed by Sandia National Laboratory uses both a neutron detector and a gamma-ray detector to provide redundancy and potentially greater assurance of accuracy in the inspection. The neutron detector uses four ^3He proportional counters in a linear array embedded in a moderating slab of polyethylene surrounded by a ^{10}B -containing material called Flex/Boron. Slabs of polyethylene are also placed on the front and rear sensors. The ^3He counters are 1 in. in diameter, and the total length is 12 in. with an active length of 11 in. This technique has been tested twice against the Peacekeeper configuration at FEW AFB in a circumferential scanning mode [4].

2.1.2 Gamma-Ray Detection.

As noted above, Sandia National Laboratory's RAPID system combines neutron and gamma-ray detectors in an attempt to improve the reliability of the inspection system. The gamma-ray detector is a 51-mm-diameter by 152-mm-length NaI(Tl) scintillation detector. NaI(Tl) was chosen as the detector material because it was readily available at Sandia, but other scintillator materials such as bismuth germinate and cesium iodide should work equally well in this system. The scintillator and its photomultiplier are mounted in a lead collimator. This technique has been tested twice against the Peacekeeper configuration at FEW AFB in a circumferential scanning mode [2].

LANL has also developed a circumferential gamma-ray scanning system referred to as passive gamma scanning (PGS). PGS has used a bismuth germinate (BGO) detector with a 76-mm-diameter and a 76-mm length. BGO was chosen for its high gamma-ray efficiency, as well as moderate energy resolution. The detector is mounted in a lead collimator. This technique was demonstrated against the Peacekeeper configuration at FEW AFB [2].

A different approach to gamma-ray detection has been proposed by Pacific Northwest Laboratory in the Cooled Optically Stimulated Luminescence (COSL) system, which was tested against the Peacekeeper configuration in August 1992. This system involves a set of gamma-ray-sensitive LiF dosimeters, which can be placed around a missile. When removed and read, these dosimeters give a mapping of the high gamma-ray emission regions surrounding the missile, thereby identifying the positions of warheads. This method does not require circumferential scanning, but does require an extensive readout process, which requires a liquid nitrogen or other cryogenic cooling system [5].

An "elephant gun" concept, proposed by researchers at LANL, makes use of a highly collimated gamma-ray detector. This instrument would be mounted at the end of a missile in its launcher and aligned in such a way that it can verify that no radiation emitter is in its line of sight. Its usefulness is limited to confirming downloading in existing systems, that is, to confirm that a warhead does not exist in a given position. Except for the collimator, this untested system would use off-the-shelf

components. Proof-of-principle testing and extensive operational concept development will be required before this technique can be reevaluated. The proposed approach of confirming the absence of warheads rather than the presence of warheads introduces a substantially different approach to others examined here [6].

2.1.3 End-On Imaging Approaches.

A number of concepts for RVOSI have been proposed that allow an image to be obtained viewing a missile end-on. All of these techniques depend on gamma detection as the basis for creating the image. The system that has been developed most fully is the Gamma-Ray Imaging System (GRIS) developed by Lawrence Livermore National Laboratory (LLNL). GRIS is based on an indirect imaging technique developed in astrophysics. The detector is a gamma-ray image intensifier, consisting of a thin CsI(Na) scintillator crystal coupled to a position-sensitive photomultiplier tube. A coded aperture optic, called a uniformly redundant array, is placed in front of the detector. This optic creates a shadow pattern that can be deconvolved to give an image, while reducing counting times significantly from those required by a simple pinhole camera. GRIS has been tested against the Peacekeeper configuration in two demonstrations at FEW AFB [7].

EG&G's HgI₂ camera has successfully counted surrogate warheads in tests at the Los Alamos Simulation Facility. The system is based on an array of HgI₂ detectors capable of room-temperature operation. The coded aperture used with this system is a Gabor zone plate. As with GRIS, deconvolution of a shadow pattern is required to create an image for warhead counting [8].

A concept for end-on imaging for the RVOSI application that surfaced during the course of the study is a Compton telescope proposed by the Institute for Space Science and Technology. This technology uses the Compton scattering of gamma rays in a pair of position-sensitive germanium detector planes (instead of a coded aperture) to produce the image. The direction of the incoming photon is determined with reconstruction software. A superposition of the projections of source cones from events in several detector pairs results in a peak that uniquely locates the source. Unlike the GRIS and the HgI₂ camera, this technology is expected to provide 3D imaging capability. The Compton telescope is undergoing proof-of-principle demonstrations in 1993 at the Naval Research Laboratory for imaging and characterizing radioactive waste containers [9,10].

We considered and chose not to review a Fourier camera concept and the Einstein camera concept, because they were either not applicable to the RVOSI task or were judged to provide no advantage over the three technologies studied.

2.1.4 Coincidence Counting.

The Fission Assay Tomography System (FATS), developed at Idaho National Engineering Laboratory, detects gamma rays emitted in coincidence following fissions in the special-nuclear materials within the warhead in pairs of detectors. FATS consists of a set of 16 Bicron Corporation BC501 liquid scintillators that discriminate between neutron and gamma-ray radiation, front-end electronics, a computer-based data-acquisition system, and analysis software. FATS uses the arrival time differences within detector pairs to establish probable positions of the fission sources (warheads). Statistical analysis of the probable positions, relative to these detector pairs, establishes a true position of the fission sources. FATS has been tested against the Peacekeeper configuration at FEW AFB [4].

2.2 ACTIVE RADIATION TECHNIQUES.

Active radiation techniques require that a radiation source (x-ray tube, gamma-ray source such as ^{60}Co , or neutron source) irradiate the inspected object and that a detector record the resulting induced, reflected, or transmitted signal. A diverse set of active radiation techniques were nominated as RVOSI candidates. In general, these technologies have been less fully explored for the RVOSI application than the passive radiation detection techniques described above.

One active radiation technique that has been extensively explored was developed for the Air Force by SRS Technologies. The SRS x-ray fluorescence system, designed for use in combination with a neutron detector (see a description in Section 2.2, *Neutron Detection*), is essentially an analysis unit based on the principle of x-ray spectroscopy. It consists of a shielded x-ray tube source and a filtered beam collimator, which is used to direct a narrow, divergent, wide-energy-band beam of x-ray photons to the outer warhead material. The x-rays interact with the very outer layer of the warhead, causing the high-Z material to fluoresce, emitting characteristic x-rays. A collimated, liquid-nitrogen-cooled, shielded x-ray detector and preamplifier detects characteristic fluorescence x-rays, thereby identifying a warhead. The complete SRS system of x-ray fluorescence and neutron detector has been tested against the Peacekeeper configuration at FFW AFB [3].

Another technology is the gamma-ray hodoscope, proposed by Argonne National Laboratory (ANL). This is a gamma-ray transmission imaging technique using tomographic reconstruction. It uses a ^{60}Co source with 32 small NaI detectors and has been demonstrated on 10 lead mockups in a Peacekeeper configuration. It detects the dense, high atomic number (Z) material of the warhead. The imaging technique typically uses a 12-angle reconstruction based on the transmission of gamma rays through the object to be imaged. Because of the intrinsic radiation generated by nuclear warheads, a background measurement must be made for the RVOSI application. Access on two sides of the missile shroud is required for implementation of this technology. Tomographic reconstruction can be completed on a laptop computer [11].

Associated particle imaging techniques have been primarily investigated for other verification applications. An associated particle technique proposed by EG&G Special Technologies Laboratory uses the direction and time correlations between fast (14-MeV) neutrons and alpha particles produced in a sealed-tube neutron generator. Detection of the alpha particle with a position-sensitive detector provides direction and time of emission of the neutron. The neutron may then interact with the target nucleus to produce a gamma ray whose energy is characteristic of the target material. The time detection of the gamma ray is used to locate the neutron-nucleus interaction in the target material, while the measurement of gamma-ray energy identifies the elemental composition. This technology allows single-sided inspection of the contents of sealed packages and containers and has been targeted at chemical munitions identification. We conducted only a preliminary evaluation of this associated particle technique because, since little testing has been conducted, we were concerned about its capabilities, as well as its intrusiveness [12].

Another implementation related to associated particle imaging is the neutron-reaction hodoscope, which ANL proposes for inspecting de-MIRVed missiles that have warheads replaced with inert objects having the same shape and mass. The neutron-reaction hodoscope induces fissions in the warheads with Cf-252 neutrons and detects the fission neutron emissions using a coarse-resolution array of detectors. Tomographic reconstruction can be completed on a laptop computer. The neu-

tron-reaction hodoscope is based on equipment developed for reactor inspection applications, but is untested for the RVOSI application. We did not rigorously review this technology; however, general observations on the gamma-ray hodoscope apply to this technology as well [13].

Radiography is a mature active radiation-detection technology for many applications, which has been reviewed for its applicability to a number of verification tasks. Equipment is commercially available for a wide range of radiographic tasks. The complexity, weight, volume, intrusiveness, and radiation hazards associated with radiography systems capable of completing the RVOSI task caused us to abandon a detailed review of this type of system [14].

2.3 ACOUSTIC TECHNIQUES.

Acoustic technologies, developed for nondestructive evaluation (NDE) and for discrimination between chemical weapons and conventional explosive shells, have only recently been suggested for the RVOSI application. These techniques are all based on the concept that any object has a number of natural resonance modes. When the object is excited by an external force with the same frequency as the resonance frequency, a small excitation will produce large-amplitude vibrations in the object. Changes in the object will change the natural resonance modes and, consequently, the response to external excitation. Three methods of exciting the front end of the missile to generate characteristic resonances corresponding to the number of RVs or warheads in place have been proposed. None of these techniques has been tested specifically for the RVOSI application.

The Acoustic Resonance Spectroscopy (ARS) approach developed by researchers at LANL employs two acoustic transducers, one for insonification and the other for reception. All of the early experiments used contact transducers; however, more recent work demonstrates that standoff operation is possible. ARS uses a sweep frequency signal as the insonification source. The measured output resulting from the insonification is the frequency response spectrum of the test object. The spectrum will exhibit peaks that correspond to resonances arising because of the physical structure of the test object and the properties of the construction materials. The resonance pattern constitutes a signature for the test object. ARS was developed as a nondestructive evaluation technique and has been fielded to distinguish chemical-agent-filled shells from high-explosive shells. Recent tests have explored the applicability of this approach to missile motor distinguishability [15-17].

The Frequency Response Measurement (FRM) system developed at LLNL measures the vibrational frequency response of a test object, as a result of insonification by an acoustic hammer containing a transducer that directly measures the impulse generated by the hammer tap. The vibration generated by the impulse is sensed by a contact transducer located elsewhere on the test object. The ratio of the measured vibration output spectrum to the spectrum of the hammer impulse is the transfer function of the test object. The transfer function spectrum will exhibit peaks and valleys as a result of resonances. The resonant frequencies are determined by the physical structure of the test object and the properties of the construction materials. The spectral pattern constitutes a signature for the test object. FRM was developed for nondestructive evaluation applications and has been tested for missile motor tagging applications as well [18,19].

Low-frequency mapping/structural vibrational response (LFM/SVR) is an alternative acoustic measurement system proposed by System Planning Corporation. In principle, LFM/SVR will operate in a standoff mode, using arrays of acoustic transducers to generate narrow acoustic beams that can be scanned over the surface of the test object. The system can scan on both transmission and

reception, or scan only on receive and insonify with a single remote source. The result of the surface scan is a map of the phase and amplitude of the re-radiated acoustic pressure field from the test object. These maps could provide a multi-dimensional signature for the test object. LFM/SVR is purely a theoretical concept at this time [1].

2.4 GRAVITY TECHNOLOGY.

Gravity meters and gravity gradiometers make use of the fact that a nuclear warhead involves a concentration of high-density material. These concentrations cause enough perturbation in the local gravitational field that a sufficiently sensitive instrument can sense the perturbation. Calculations indicate that a sensitive instrument should be able to sense the gravitational perturbations introduced by RVs in a missile. Proximity of the instrument to the missile will be crucial in achieving the required measurement.

Gravity meters, based on a mature technology, have been developed for oilwell surveys, mineral detection, inertial navigation, and refinement of standard measurement units. Although gravity meters are well developed, they lack adequate sensitivity for the RVOSI application.

Development over the past 20 years of gravity gradiometers, which measure the spatial derivative of the gravitational acceleration, has yielded instruments that may have the sensitivity to perform the RVOSI task. With the exception of a Bell Textron instrument, gravity gradiometers exist only as laboratory research instruments. The most sensitive of these instruments require cryogenics for operation. Evaluation of the gravity gradiometry technology was based on experimental data being developed at the University of Maryland, College Park, and on development projections from several industrial research laboratories, including Bell Textron, Draper Laboratory, GWR, and Product Development Technology (PDT) Corporation. Characteristics of various gravity gradiometers are summarized in the START Signature Exploitation Systems Analysis final technical report [1].

SECTION 3 EVALUATION FACTORS

In order to focus the study, we developed five evaluation factors. These factors generally reflect desirable characteristics for RVOSI technologies, although an attempt was made to make a semi-quantitative comparison without making a good-versus-bad judgment in the early stages of the study. We were concerned early in our study about export control policy and its relationship to the technologies being discussed, but we found none of the evaluated technologies to be limited under current regulations. We originally proposed as an evaluation factor applicability to the wide variety of missile systems that will require RVOSI, but we deferred this to the later decision-tree evaluation process. The five evaluation factors are confidence, cost, intrusiveness, operational impact, and inspector's burden.

3.1 CONFIDENCE FACTOR.

The first and most important evaluation factor we identified is the confidence that can be placed in the inspection method. For any inspection to be successful, the inspectors and inspected parties must have high confidence that the results of the inspection are conclusive. In order to evaluate this factor, we discussed two main areas—reliability and spoof resistance. The two areas were closely inter-leaved and often overlapped in the final evaluation.

In evaluating the reliability, we set the standard that one measurement should result in one correct RV count. We set this standard to address the intrinsic reliability of the technology proposed, the spoofability of the technology, and the danger of false positive readings. A major factor we considered in evaluating the reliability of the technology was the level of maturity the technology had achieved. Many of the technologies studied have been extensively field tested against the Peace-keeper missile system at FEW AFB, while other proposed technologies are in the conceptual stage. Another issue we associated with the reliability of the system was the level of baseline information that must be obtained from field tests for the technology to be viable. The requirement to match collected data to a template produced a basic distinction between classes of technologies.

We considered the spoof resistance of the technologies from two standpoints. First, we considered whether a reasonable missile/warhead configuration could cause a technology to obtain an acceptable reading when a non-treaty-compliant configuration exists. Second, we addressed the issue of misleading readings through equipment tampering and/or misuse of inspection protocols. Finally, we tempered these considerations by considering whether the political implications of a spoof justified the complications of the spoof attempt.

At the conclusion of the study, the evaluation factor of confidence in technologies for the RVOSI task remained the primary concern and motivated our highest priority recommendations.

3.2 COST FACTOR.

A major motivation for this study was to determine whether the use of RVOSI technologies could reduce the cost of on-site inspections. This portion of the study was conducted primarily by the Institute for Defense Analyses (IDA), who attempted to address what impact the use of a technology would have on operational costs, as well as the cost of developing, procuring, maintaining, and

operating inspection equipment over a 15-year period of 10 RVOSIs per year. We incorporated input from the Air Force and Navy when possible. The sources for technology development costs were individual technology developers. Cost considerations, although a driving force at the beginning of this study, were only a minor factor in our recommendations.

3.3 INTRUSIVENESS FACTOR.

In negotiating an inspection methodology, reciprocity is of prime importance. The desire is to unambiguously provide the data required for the inspection, while revealing no additional data. We addressed this issue under the third evaluation factor, intrusiveness. Since any technology that the U.S. proposes for treaty verification can be used by Russian inspectors on our systems, intrusiveness is a major national security concern. We considered NSA and service concerns on security issues in our evaluations, although we weighted a technology's ability to perform a unique inspection task more heavily than intrusiveness concerns in the overall evaluations. Intrusiveness issues we considered included what formally classified data were collected by a technology, what operational security issues each technology might compromise, and what the intrusiveness implications were of requiring on-site inspectors. Another intrusiveness issue we discussed was whether technologies could be used to mask gathered information beyond that required for the inspection. Intrusiveness concerns resulted in several of our future research recommendations.

3.4 OPERATIONAL IMPACT FACTOR.

We closely linked the operational impact evaluation factor with both the cost and intrusiveness factors. Our primary concerns associated with this factor were how long base operations would be affected by the RVOSI procedure and how access required to the missile and launcher would be affected by the use of a technology. Our early concerns about data analysis time were largely eliminated during the course of our study, so inspection time requirements were dominated by equipment setup times and actual data collection times. Operational impact was an important factor in the ranking of proposed technologies in the study.

3.5 INSPECTOR'S BURDEN FACTOR.

The final factor, inspector's burden, was somewhat premature as an evaluation factor, but did help to identify important future development issues. The adoption of any technology studied will require some redesign of the system to optimize it for the RVOSI task. Features of inspection systems that strongly affect the inspector's burden include weight and volume; ease of use, including setup, calibration, data collection, data analysis, and maintenance; operational safety of the system; special requirements, such as power sources, any special materials, and special-purpose mounting fixtures or vehicles; and durability and ruggedness. Some of these features can be significantly affected by design, and some are intrinsic to the technology. In the study, we tried to identify technologies that cannot be redesigned, and those that would benefit from additional development.

SECTION 4

EVALUATION OF THE START VISUAL INSPECTION PROTOCOL

As noted in the introduction of this report, START specifies visual inspections for the RVOSI task. Demonstrations of visual inspections on silo-based and submarine-launched ballistic missiles (SLBMs) have been conducted in both the U.S. and the Former Soviet Union (FSU). Detailed protocols for these inspections have been developed and all parties have expressed satisfaction with this method of verifying the attribution criterion specified in START. The visual inspection method requires that the missile be adequately exposed from its launcher so that any ascent shrouds surrounding the RVs can be removed and a physical count of the RVs can be made. Drapes or hard covers are allowed so that features of the reentry vehicles and mounting bus are hidden from view.

The visual inspection procedure is particularly cumbersome for the Peacekeeper missile. The procedure requires the removal of the missile front end and the transport of the front end to a special missile-handling facility where the shroud is removed. The reentry vehicles are covered with soft covers and the bus is covered with a drape to obscure the details of the bus. For the Minuteman II (MMII), Minuteman III (MMIII) and SLBMs, procedures have been developed that allow the missile to stay in the silo or launch tube. The shroud is removed and covers are placed over the RVs and other details that do not need to be viewed for treaty verification. The visual inspection procedure takes the missile out of service for approximately 3 days for the Peacekeeper, 12 hours for the MMIII, and 24 hours for SLBMs [20,21].

Visual inspection demonstrations in the FSU indicate that the Russians have developed procedures that require removal of the front end from both SLBMs and silo-based missiles. The front ends were placed nearby, the shroud was removed, and the RVs were covered. The front ends remained exposed to the weather, a situation the U.S. is unwilling to tolerate for its own equipment. U.S. inspectors were on Russian missile sites for 8 to 10 hours for these inspections [22,23].

Many aspects of the visual inspection protocol will be used regardless of the method used to determine the RV count. Since this is the alternative against which each technology solution to the RVOSI problem is measured, we began our initial evaluations by considering the START visual inspection protocol against our evaluation factors.

4.1 CONFIDENCE IN VISUAL INSPECTION METHODS.

The basis of the visual inspection protocol is that RVs mounted on a missile have identifiable sizes and shapes. For developed systems, this is a reasonable assumption since inspectors know, in general, what RVs in a missile front end look like. Demonstrations of visual inspections in both the U.S. and the FSU satisfied those involved that this is a viable inspection technique. False positives are of little concern for the visual inspection method, because inspectors are accustomed to relying on their eyes for information and because backup procedures are specified if an unidentified RV-sized object is found. It is accepted that difficulties associated with poor visibility due to weather conditions, and obstructions due to placement of missile handling equipment, do not compromise the reliability of the inspection, although these concerns stimulate interest in a technology solution to the RVOSI problem.

Spoofting related to the visual-inspection method has been considered extensively and is primarily tied to scenarios for covert removal of warheads as the missile is opened to reveal the front end and RVs are covered. Inspection protocols and operational restrictions when an inspection is announced have been carefully negotiated to assure both inspected party and inspector that the missile front end being viewed is the same front end with the same number of RVs that was in the launcher. The same protocols and operational controls that have been approved for visual inspections are expected to be followed in any RVOSI using technologies.

4.2 COST OF VISUAL INSPECTIONS.

Costs developed for the visual inspection methods are based on Air Force approaches developed for RVOSI under START. These procedures were reviewed and cost estimates prepared by Wayne Schroeder of RDA in 1989, as reported in *Technical and Cost Considerations for Reentry Vehicle On-Site Inspection* [24]. IDA reviewed the assumptions made for these cost estimates and updated them based on recent information from service representatives. Resulting cost estimates for 10 inspections per year conducted over a treaty lifetime of 15 years are approximately \$30 million for inspections in the FSU and \$15 to \$20 M for inspections in the U.S. For inspections in the FSU, the costs to the U.S. are entirely attributable to OSIA for providing on-site inspectors. For inspections in the U.S., costs are dominated by costs for site preparation and for OSIA escorts for Russian inspectors. Details of these cost estimates can be found in the draft report *Cost Implications of Technologies for Reentry Vehicle On-Site Inspections*, submitted by IDA in January 1993 [26]. Although detailed information from the Navy to formulate similarly detailed cost estimates was never forthcoming, descriptions of the visual inspection procedures developed by the Navy for RVOSI under START lead us to believe that OSIA costs will dominate for inspections in the FSU, and that site preparation and OSIA escorts will dominate costs for inspections in the U.S. for this case as well [25].

Technologies that reduce the time required for an inspection by reducing the operations required on a missile system or that reduce the number of inspectors needed would have the greatest cost-reducing impact for inspections conducted in the U.S. For example, for Peacekeeper inspections, the ability to leave the front end and shroud in place would decrease inspection costs by approximately 10 percent. For MIII inspections, the ability to leave the shroud in place would reduce costs by only 1 to 2 percent [26].

4.3 INTRUSIVENESS OF VISUAL INSPECTION PROTOCOL.

Visual inspections are intrusive simply because the inspectors are on-site. Knowledgeable inspectors, since they are on-site and cognizant of the general procedures being executed, can infer a great deal about base operations, readiness, and established operating procedures. The layout of a base and the differences between it and a base in the inspector's home country can reveal overall defense policy. During demonstrations in both the U.S. and the FSU, both nations covered a great deal of equipment characteristic of base operations, with camouflaging material to prevent inspectors from access to just this type of information. Any inspection technique that requires on-site inspectors will require similar site preparations.

Another intrusiveness concern associated with on-site inspectors is either accidental damage to missile equipment or intentional sabotage. All proposed visual protocols, both in the U.S. and in the

FSU, allow inspectors to look into the launcher, either for the actual RVOSI or to ensure that no RVs remain in place when the front end is removed for inspection. Draping has been developed that satisfies U.S. concerns regarding this type of intrusiveness. This draping is sufficiently sturdy to catch any items that might fall into the launcher and provides electromagnetic shielding for sensitive components.

4.4 OPERATIONAL IMPACT OF VISUAL INSPECTION PROTOCOL.

The key consideration for operational impact is the amount of time that normal base operations have to be suspended for an RVOSI to be completed. As noted in the description of visual inspections, the time for these operations can range from eight hours to three days, depending on the amount of missile disassembly required to reveal the RVs. In addition, the U.S. site where the inspections occur will be closed for normal operations to prepare for the Russian inspectors' visit. Shrouding operations for equipment not directly used in the inspection is required, as well as other operations to eliminate the compromise of sensitive operational information. In fact, we have determined that these site preparation steps account for a significant part of the RVOSI cost. Elimination of some disassembly steps, especially for the Peacekeeper configuration, would simplify operations associated with RVOSI. Information from the Air Force indicates that a technology that allows the missile shroud to remain in place or that allows the missile front end to remain in place would provide an operational advantage over the current visual inspection techniques. In the inspections demonstrated in the FSU, the time involved for observed operations leads us to believe that leaving the missile front end in place and leaving the missile shroud intact would reduce the time required for these inspections as well. The Navy informed us that leaving the shroud in place would result in only a minor time savings [24].

4.5 INSPECTOR'S BURDEN UNDER VISUAL INSPECTION PROTOCOL.

A primary advantage of the visual protocol is that it does not require the inspector to carry any special inspection equipment onto the site. A substantial amount of inspector discretion is required to decide whether any suspicious items are present at the inspection site and to observe for potential deception or RV concealment. Inspectors have little trouble observing such potential problems and evaluating possible sources of error [27].

SECTION 5

RVOSI TECHNOLOGY EVALUATIONS

This section discusses the merits of the RVOSI technology candidates identified for this study as compared to the evaluation factors. In some cases, individual technologies are grouped by the signature each technology uses for RV counting. When distinctions between individual technology implementations are important, they are discussed as individual technologies. The technologies that were fully evaluated and that are discussed here follow.

Passive Radiation Detection Techniques

Circumferential Neutron Scanning

PNS

SRS/BMO

DND

RAPID

Circumferential Gamma-Ray Scanning

RAPID

PGS

COSL

End-On Gamma-Ray Imaging

GRIS

HgI₂

Compton Telescope

Elephant Gun

Coincidence Counting/FATS

Active Radiation Techniques

X-Ray Fluorescence

Hodoscope

Associated Particle Imaging

Acoustic Techniques

ARS

FRM

LFM/SVR

Gravity Gradiometry

The preliminary evaluations of these technologies completed by individual team members, along with the evaluation matrix that reviewers considered, are included in Appendix A and summarized in the following sections.

5.1 CONFIDENCE.

As indicated previously, the relative maturity of various technologies greatly affected our ability to evaluate confidence. We chose technologies that had the theoretical potential to give an adequate signature for an RVOSI. Table 5-1 shows several methods we used to assess the relative maturity of the technologies and to assess the confidence that could be placed in them.

Table 5-1. Maturity of RVOSI technologies.

Inspection methods		Phenomenology for RVOSI understood	Test data collected for RVOSI	Demonstration model of field instrument	Unique signature for RVOSI
Passive radiation					
<i>Neutron scanning</i>					
PNS		Yes	FEW	RVOSI	Moderate
SRS/BMO		Yes	FEW	RVOSI	Moderate
DND		Yes	FEW	RVOSI	Poor
RAPID		Yes	FEW	RVOSI	Moderate
<i>Gamma-ray scanning</i>					
RAPID		Yes	FEW	RVOSI	Good
PGS		Yes	FEW	RVOSI	Good
COSL		Yes	FEW	RVOSI	Moderate
<i>Gamma imaging</i>					
GRIS		Yes	FEW	RVOSI	Moderate
HgI ₂		Yes	LANL SIM	RVOSI	Moderate
Compton telescope	No	None	None	Unknown	
Elephant gun		Yes	None	None	Unknown
Coincidence counting/FATS		Yes	FEW	RVOSI	Moderate
Active radiation					
<i>X-ray fluorescence</i>		Yes	FEW	RVOSI	Good
<i>Hodoscope</i>		Yes	LANL SIM	None	Good
<i>Associated particle</i>		No	None	None	Unknown
Acoustic					
ARS		No	None	CW	Unknown
FRM	No	None	CW	Unknown	
LFM/SVR		No	None	None	Unknown
Gravity gradiometer		Yes/calculations	Lab	Oil well	Unknown

FEW—F. E. Warren Air Force Base

LANL SIM—Los Alamos National Laboratory Simulation Facility

For most technologies considered, the phenomenology involved in generating the treaty verification signature is well understood in the RVOSI context. Exceptions to this include the Compton telescope, associated particle imaging techniques, and all acoustic techniques. Proof of principle for the RVOSI application is still required before any definitive comment can be made on the ability of these technologies to complete the RVOSI task. We had sufficient questions regarding the ability of associated particle imaging techniques to successfully complete the task to eliminate these technologies for the remainder of the study. After extensive study, we continue to question whether missile front ends will generate an unambiguously identifiable acoustic signature related to RV count.

Some technologies have been extensively tested for RVOSI-like applications. Others have been developed primarily for other applications. The data that the team found most useful for evaluating confidence come from the two tests, sponsored by the DOE Office of Arms Control and Proliferation, conducted on a Peacekeeper missile at FEW AFB. Other technologies have been tested for RVOSI-like configurations, either in the laboratory or at the Los Alamos National Laboratory Simulation Facility (LANL SIM). From these data, circumferential gamma-ray scanning and active

radiation techniques produced the clearest and least ambiguous signals. These technologies are ranked "good" for RVOSI signature uniqueness. Numerous other passive radiation-detection techniques gave sufficiently distinguishable signals to be judged adequate (ranked moderate for signature uniqueness) for the RVOSI task, assuming that future confidence-building studies continue to show good results. The elephant gun and gravity gradiometry techniques, along with those techniques that still require proof of principle, cannot be judged regarding confidence for RVOSI because not enough data exist.

None of the technologies studied are considered to exist as fieldable systems suitable for RVOSI. Demonstration models of fieldable systems have been advanced for a number of the technologies, either for the RVOSI task or for other tasks. This is discussed further in Section 5.4, *Operational Impact*, and 5.5, *Inspector's Burden*. An advanced development program will be required for any of these technologies to be implemented for a treaty verification task.

All of the technologies require some kind of demonstration measurement to establish a baseline for actual inspections. Most technologies produce signatures that indicate the number of warhead/RVs, or some sort of image from which a count can be made, either visually or through a pattern recognition algorithm. In the case of acoustic techniques, the signature does not allow for a specific count so templating for all allowable configurations is required. The acceptability, reproducibility, and uniqueness of these signatures raise technical concerns regarding the confidence that can be placed in acoustic techniques.

Insufficient data have been collected on any technology for its probability of producing false positive readings to be assessed. The concern with false positives is significant because of the political implications of a such a reading, and because the data interpretation is required for an inspection using technologies with signatures not well defined. Whereas inspectors are accustomed to depending on their eyes, most are less familiar, if not totally unfamiliar, with the type of signals provided by these RVOSI technologies. Signal processing associated with some variant of automatic signal recognition and further statistical data gathering will both be required before the danger of false positives can be assessed.

Spoof resistance has not been adequately addressed for any technology, especially in light of the reduced number of warheads that missiles may carry as specified in START II. Analysis of weapon system configuration is required to study spoof resistance. Protocols developed for visual inspections provide safeguards against most operational spoofing techniques, leaving only concerns regarding spoofing methods that would mask or falsify the acceptable signature. In considering spoof resistance of technologies in general, we concluded that most of the studied techniques would be difficult to spoof, assuming that techniques similar to current U.S. weapons design practices dominate present and future Russian designs. (A possible exception is for acoustic techniques, since this is so heavily linked to template matching.) For all of these technologies, the political consequences of an unsuccessful spoof appear to be sufficiently risky that we do not feel the danger of spoofing should eliminate any technology.

Confidence, and our inability to fully evaluate this factor because of a lack of data, was a major driver for the additional analysis we conducted. The decision-tree process (see Section 6) was heavily influenced by issues raised in the discussion of the confidence evaluation factor. As we considered the new treaty requirements introduced in START II, enhanced inspection confidence became the driving factor for RVOSI technology research and development.

5.2 COST.

The use of any technology is unlikely to offer substantial cost savings over the START visual inspection protocol. As discussed previously, the cost of inspections in the FSU is dominated by the cost of providing on-site inspectors. The use of technologies will not eliminate this need. In fact, inspection teams will need to transport and operate equipment. The number of inspectors allowed is expected to remain constant.

The use of technology is likely to increase the marginal cost of RVOSI somewhat. However, most technologies appear to have low life-cycle costs. Table 5-2 summarizes the costs for development, procurement, and annual operations and maintenance, provided to IDA by the developers of the

Table 5-2. Costs of RVOSI technologies.

Inspection methods	Cost to develop (\$M)	Procurement cost (\$M)	Annual O&M cost (\$M)	15-year costs* (\$M)
Passive radiation				
<i>Neutron scanning</i>				
PNS	1	0.1	0.01	5
SRS/BMO	2	0.5	0.5	75
DND	0.4	0.2	0.02	6
RAPID	0.03	0.03	0.003	1
<i>Gamma-ray scanning</i>				
RAPID	0.03	0.03	0.003	1
PGS	0.2	0.02	0.01	3
COSL	0.9	0.04	0.005	3
<i>Gamma imaging</i>				
GRIS	1.5	0.3	0.03	9
HgI ₂	0.2	0.2	0.03	10
Compton telescope	5	1.1	0.045	20
Elephant gun	0.5	0.02	0.01	3
<i>Coincidence counting/FATS</i>	3	0.3	0.01	9
Active radiation				
<i>X-ray fluorescence</i>	2	0.5	0.5	75
<i>Hodoscope</i>	0.6	0.3	0.01	5
Acoustic				
ARS	0.8	0.04	0.01	4
FRM	1	0.15	0.02	7
LFM/SVR	2	0.01	0.001	2
Gravity gradiometer				
<i>Bell Textron</i>	2.8	1.0	0.1	30
<i>Draper Lab</i>	6	7	0.5	200
<i>GWR Instruments</i>	2.5	1.0	0.2	70
<i>PDT</i>	1.8	0.6	0.5	80

*15-year undiscounted cost for 10 sets.

technologies. These costs were combined to determine the 15-year costs. Numerous assumptions are included in these 15-year costs, as reported in *Cost Implications of Technologies for Reentry Vehicle On-Site Inspections* [26]:

- 1. We are assuming that, if used for RVOSI, 10 equipment sets will be procured by the on-site inspection agency. Two of these will be located at the eastern point of entry to the FSU, two at the western point of entry, and the remainder centrally located in the U.S.*
- 2. Equipment built during the development stage is considered prototype and not part of the 10-set quantity.*
- 3. The quantity of interest is 15-year system costs—15 years being nominal treaty duration. System costs are (1) the sum of development costs (excepting sunk costs as of FY 92), (2) the procurement costs for 10 sets, adjusted by the requirement to procure new systems if the lifetime of those systems is less than 15 years, and (3) the annual operating costs for the 10 units over 15 years.*
- 4. All cost data provided to the study team are in FY 92 dollars.*
- 5. Since the estimates that have been provided are rough at best, all system costs will be reported to one, or at most two, significant figures.*
- 6. Although in many cases ranges of costs were provided, we are making point estimates, recognizing that in all cases there are greater or lesser bands of uncertainty around all estimates [25].*

Figure 5-1 shows the 15-year costs versus time to develop a fieldable system. The questionnaires from which this information was drawn are included in a report by Grotte and Klare [25]. The \$200M Draper Laboratory gravity gradiometer is omitted to allow for more effective display of the other information. Also noted are baseline levels for visual inspection costs, both in the U.S. and the FSU, assuming 10 inspections per year over 15 years.

Most technologies appear to have life-cycle costs under \$20M over the 15-year period considered. The notable exceptions to this are the gravity gradiometer cost estimates, which are high for all development, procurement, and, particularly, O&M. Some of this high cost is anticipated because of the immaturity of this technology compared to the others.

As discussed in the evaluation of visual inspections, the driving costs incurred during visual inspections will be incurred for technology inspections. Consequently, the costs listed in Table 5-2 should be added to visual inspection costs. We determined that technology system costs were a neutral factor in evaluating the technologies. Comparative technology costs may become a factor in choosing between technologies based on increased effectiveness over visual inspections or to provide capabilities that visual inspections cannot. However, cost is not a driving motivation for technology selection.

5.3 INTRUSIVENESS.

Intrusiveness considerations for technology approaches to RVOSI were dominated by the concern that technologies would reveal more information than that required for treaty verification and the concern that classified nuclear weapons design data would be revealed. Table 5-3 summarizes some

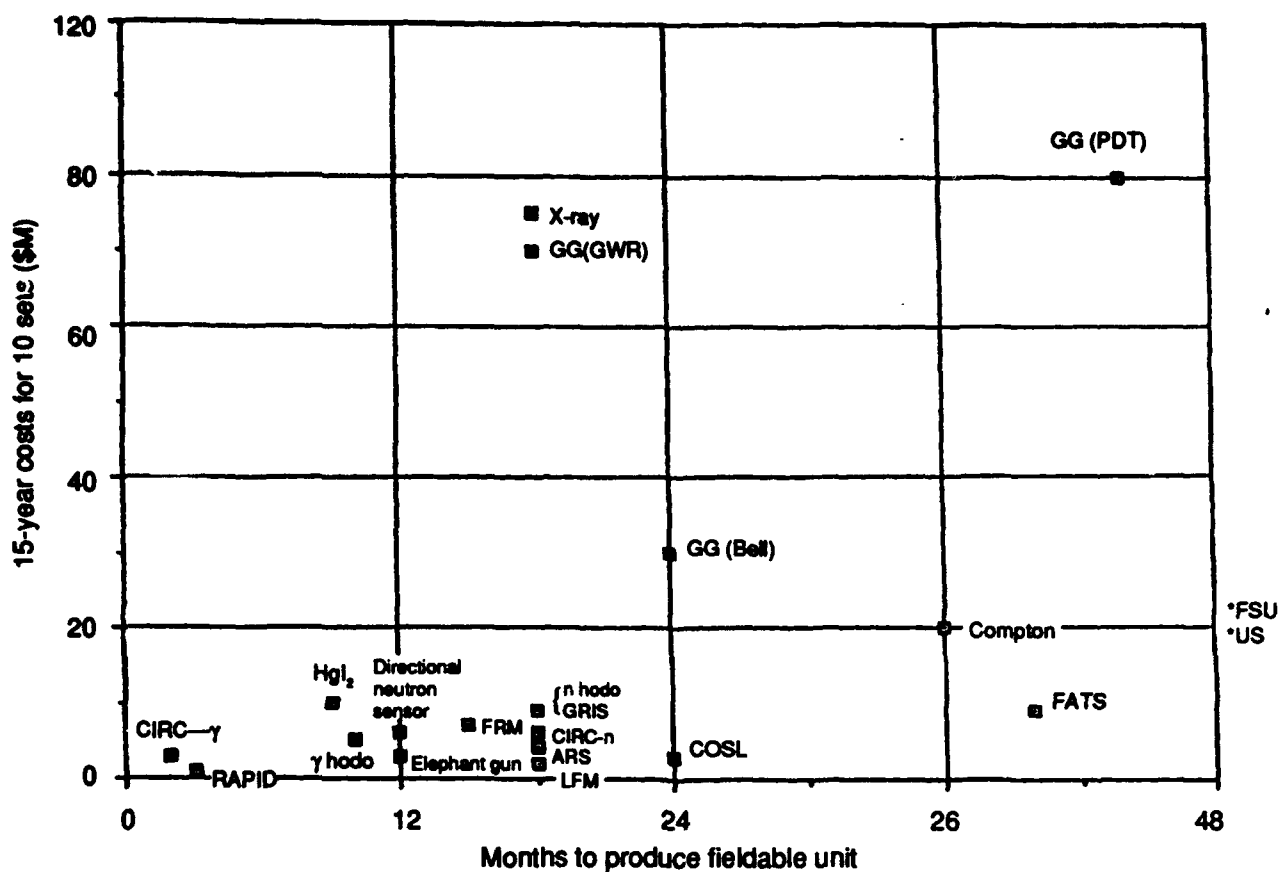


Figure 5-1. 15-year costs for technologies.

of the intrusiveness issues we considered. Two concerns were driven by START restrictions on the information that can be made available to inspectors. First, START specifies a "not-more-than" attribution condition, which is violated by most technology approaches. In the visual protocol, hard covers can allow a not-more-than X count of warheads, while concealing the actual number if it is less than X . As shown in Table 5-3, all technologies except the elephant gun, and possibly acoustic technologies, will require some data processing to conceal an actual RV/warhead count. Second, START does not allow inspectors to obtain an image of the inspected items. A number of the technologies considered do create an image (based on the gamma-ray emissions of the warheads). Although both of these are serious concerns, we decided to proceed with the assumption that with proper data processing of the signature obtained from the technology, the intrusive information could be masked from the inspectors and technologies could be made acceptable from an intrusiveness standpoint.

The concept of masking gathered data also had an effect on our evaluation of technologies involving radiation detection. In discussions of gamma-ray detection methods, significant concern has been expressed regarding compromise of weapons design information through revelation of the gamma spectrum emitted by a warhead. Since gamma-ray detection technologies have, both theoretically and in practice, the greatest ability to spatially resolve warheads for the RVOSI task, we continued to consider them with the assumption that some data processing algorithm could be adapted to mask from inspectors any data not needed to count the warheads. Neutron detection techniques may also reveal sensitive information, although these data can also theoretically be masked.

Table 5-3. Intrusiveness concerns for RVOSI technologies.

Inspection methods	<X masking required*	Image generated	Additional information required/acquired
Passive radiation			
<i>Neutron scanning</i>			Neutron dose rate
PNS	Yes	No	
SRS/BMO	Yes	No	
DND	Yes	No	
RAPID	Yes	No	
<i>Gamma-ray scanning</i>			Gamma spectrum and dose rate
RAPID	Yes	No	
PGS	Yes	No	
COSL	Yes	No	
<i>Gamma imaging</i>			Gamma spectrum and dose rate
GRIS	Yes	Yes	
HgI ₂	Yes	Yes	
Compton telescope	Yes		
Elephant gun	No	No	
<i>Coincidence counting/FATS</i>	Yes	Yes	
Active radiation			
<i>X-ray fluorescence</i>	Yes	No	Gamma spectrum Radiation case material
<i>Hodoscope</i>	Yes	Yes	Warhead centerline
Acoustic			
ARS	Unknown	No	Extensive template collection
FRM	Unknown	No	
LFM/SVR	Unknown	No	
Gravity gradiometer	Yes	No	Insufficiently studied

*X = the attributed number of RVs for a missile system.

Two intrusiveness issues we were unable to resolve by recommending advanced data processing studies are characteristic of active radiation techniques and acoustic techniques. Active radiation techniques require that energy (x-ray, gamma-ray, or neutron) be introduced into the front end of the missile to produce the required signature. This introduction of energy raises the concern of accidental damage to missile electronics or intentional sabotage. Although we doubt that the energy associated with these techniques would cause accidental damage, assuring that no damage would occur makes these technologies unattractive from the intrusiveness standpoint.

Procedures required to baseline the acoustic techniques introduce a unique intrusiveness problem. For acoustic techniques to be viable, we assume that each allowable missile/warhead configuration has a unique structural response. Consequently, templates would have to be developed for all allowable configurations. That is to say, if a missile is attributed to carry 10 warheads, that missile would have to be templated in all configurations with 10 or fewer warheads that the inspected nation plans to field. Although we can imagine processing that would mask which template was matched in an inspection, the original templating process would be quite intrusive. As missiles are downloaded, and especially if the only allowable configuration has one warhead, this type of intrusiveness may become less of a problem. The level of this type of intrusiveness cannot be assessed until proof of principle has been demonstrated for acoustic RVOSI measurements.

5.4 OPERATIONAL IMPACT.

Operational impact, primarily characterized in this study by system downtime, should be reduced for RVOSI operations if, throughout the inspection, the missile, front end, and shroud can stay in place within the launcher. All of the technologies examined in this study allow the shroud to remain in place. However, all technologies require that the submarine launch tube cover or silo door be opened for an inspection. There is some speculation that gravity gradiometry techniques could complete inspections through a silo door or launch tube cover, but this claim by the System Planning Corporation (SPC) is unproven at this time and most of our team is skeptical of this claim. The determining characteristic between technologies is the proximity that the instruments must have to the missile front end for the inspection to be completed. Table 5-4 characterizes the technologies evaluated with regard to proximity requirements and time factors for inspections. Technologies with proximities of 5 m were characterized as not requiring front end removal from launchers. Those that must be within a few feet of the front end probably will require that the front end be removed from the launcher,

Table 5-4. Operational considerations for RVOSI technologies.

Inspection methods	Instrument proximity (m)	Setup time (hr)	Data collection time (hr)	Host support
Passive radiation				
<i>Neutron scanning</i>				
PNS	~1	3	4	Install instrument
SRS/BMO	~1	2	2	Install support structure
DND	~1	1	2	Install instrument
RAPID	~1	1	2	Install instrument
<i>Gamma-ray scanning</i>				
RAPID	~1	1	1	Install instrument
PGS	~1	3	1	Install instrument
COSL	~1	2	6	Install detectors
<i>Gamma imaging</i>				
GRIS	5	1	4	Install support structure
HgI ₂	5	1	6	Install support structure
Compton telescope	5	1	4	Install support structure
Elephant gun	5	TBD	TBD	TBD
<i>Coincidence counting/FATS</i>	~1	2	6	Complex alignment of detectors
Active radiation				
<i>X-ray fluorescence</i>	~1	2	2	Install support structure
<i>Hodoscope</i>	~1	2	2	Install instrument and extensive alignment
Acoustic				
ARS	Contact	2	<1	Install detectors
FRM	Contact	2	<1	Install instrument
LFM/ISVR	5	3	<1	None
Gravity gradiometer	~1	TBD	TBD	TBD

although modifications could possibly be made, particularly in the gamma-ray scanning techniques, to eliminate this requirement. The acoustic techniques that require contact with the missile front end can probably be installed by the host nation with the missile remaining in place.

The time factors listed in Table 5-4 give a comparison between the technologies. Setup times assume that the missile front end can stay in the launcher for the inspection. As noted previously, this is probably not reasonable for technologies where closer proximity is required. If the missile front end can stay in place, all of the technologies appear to be viable from a time standpoint, requiring three to eight hours for setup and data collection. If the missile front end must be removed from the launcher for the inspection, technologies would offer little advantage over visual protocols from a time standpoint.

For most technology inspections, some setup operations will require support from the host nation. This is usually a straightforward installation of an instrument or a support structure for an instrument. In cases where detectors must be placed, precise positioning will be very important. The unwillingness of our own services to allow equipment in close proximity to missile front ends is a matter which will have to be considered if a technology is chosen. From the standpoint of safety and inspection confidence, we believe that this situation can be satisfactorily addressed: if we want to enhance inspection confidence using a technology, we may have to allow equipment close to our missiles for the sake of conducting a technology inspection. For inspections in the FSU, we are unable to assess safety concerns that may exist regarding placement of instruments near a fully configured missile. We suspect that there are indeed some safety concerns, but, again, if enhanced inspection confidence is a desired outcome, these concerns can probably be satisfactorily resolved.

5.5 INSPECTOR'S BURDEN.

For this evaluation factor, technologies offer no advantages; in fact, they have some clear disadvantages over visual inspections. All technologies require more equipment than visual inspections. All of the technologies reviewed require personal computer support and a power supply. Some also require cryogenics. The design of man-portable gear should be addressed when a technology is selected for advanced development. For all of the technologies studied, we agree that current prototype systems could be more efficiently designed to optimize safety, low maintenance, ease of use in the field, and portability. Safety concerns are particularly important for inspections in the FSU, since we are unfamiliar with industrial safety standards there. Our information indicates that industrial safety is not as well regulated in the FSU as it is in the U.S.

Another issue that affects the inspector's burden is how easily the signature produced in a technology inspection can be verified. Inspectors are accustomed to using their eyes as instruments. When signatures are collected in technology demonstrations, a certain level of judgment is often used in interpreting the data. One technology, COSL, does not immediately produce an inspection result. Unless this condition can be remedied, COSL is a poor candidate for the RVOSI task. Some form of automatic signature recognition algorithm would relieve inspectors of the burden of deciding when a signature is adequate for treaty verification. Automatic signature recognition may also be required to limit intrusiveness and to eliminate the need for extensive inspector training.

5.6 SUMMARY OF TECHNOLOGY EVALUATIONS.

Based on the five evaluation factors, we concluded only that no technology is obviously superior to the visual protocols, nor do any have all the attributes to make it stand out from the others. The following discussion summarizes the results of the technology evaluations.

Passive radiation-detection techniques as a group appear to be able to complete the RVOSI task, with gamma-ray scanning and imaging providing the most definitive signatures. The maturity level of this type of instrument is generally high, most having been demonstrated at FEW AFB against the Peacekeeper. The cost of these systems is not prohibitive. Intrusiveness is a continuing concern, particularly with those techniques that require gamma-ray detection. Several of these technologies were specifically designed for end-on operation, which is desirable operationally.

Active radiation techniques also have been demonstrated to adequately complete the RVOSI task. This is another relatively mature class of technologies. Safety and intrusiveness concerns associated with the radiation to which the missile and warheads must be exposed is a continuing concern for these technologies. The x-ray fluorescence system was designed for nearly end-on operation, since it is based on circumferential scanning at a high angle relative to the plane of the warheads.

Acoustic techniques are unproven for the RVOSI application. These approaches tend to be inexpensive and lightweight. The acceptability of extensive templating of missile systems for these technologies is unknown. These techniques, if proven effective, could be used with the missile in the launcher.

Gravity gradiometry, another immature technology for the RVOSI application, appears to be very expensive. Development of a fieldable system and proof of its applicability for in-launcher inspections will require extensive work. Intrusiveness is not a major concern for this technology, but identification of high-mass objects that are not warheads may lead to inaccurate results.

These evaluations were used to develop research recommendations based on a decision-tree process, which we used to rank and eliminate various technology approaches.

SECTION 6

RVOSI TECHNOLOGY STUDY DECISION-TREE PROCESS

The decision-tree process was adopted so the team could examine individual technologies against specific verification tasks that the team felt were possible applications. These tasks were considered for specific missile configurations, to identify issues not addressed by the Peacekeeper experiments at FEW AFB. Figure 6-1 shows the decision tree we considered.

We chose inspection objectives for the decision-tree process that reflected START verification requirements, concerns about verification of downloading associated with START, and new de-MIRVing and downloading requirements associated with START II. We discussed a number of inspection objectives, which resulted in our considering four inspection objectives: counting the number of RVs on a missile, counting the number of nuclear warheads on a missile, confirming downloading, and confirming bus changes. The issue of dealing with the "not more than the attributed number" criterion set in START was not considered as a separate objective from counting warheads or RVs. As discussed, regarding the intrusiveness evaluation factor, we assumed that an actual count of RVs or warheads could be converted to a "not more than X" readout. Each of these objectives was considered for three missile configurations: silo-based, mobile, and sub-launched.

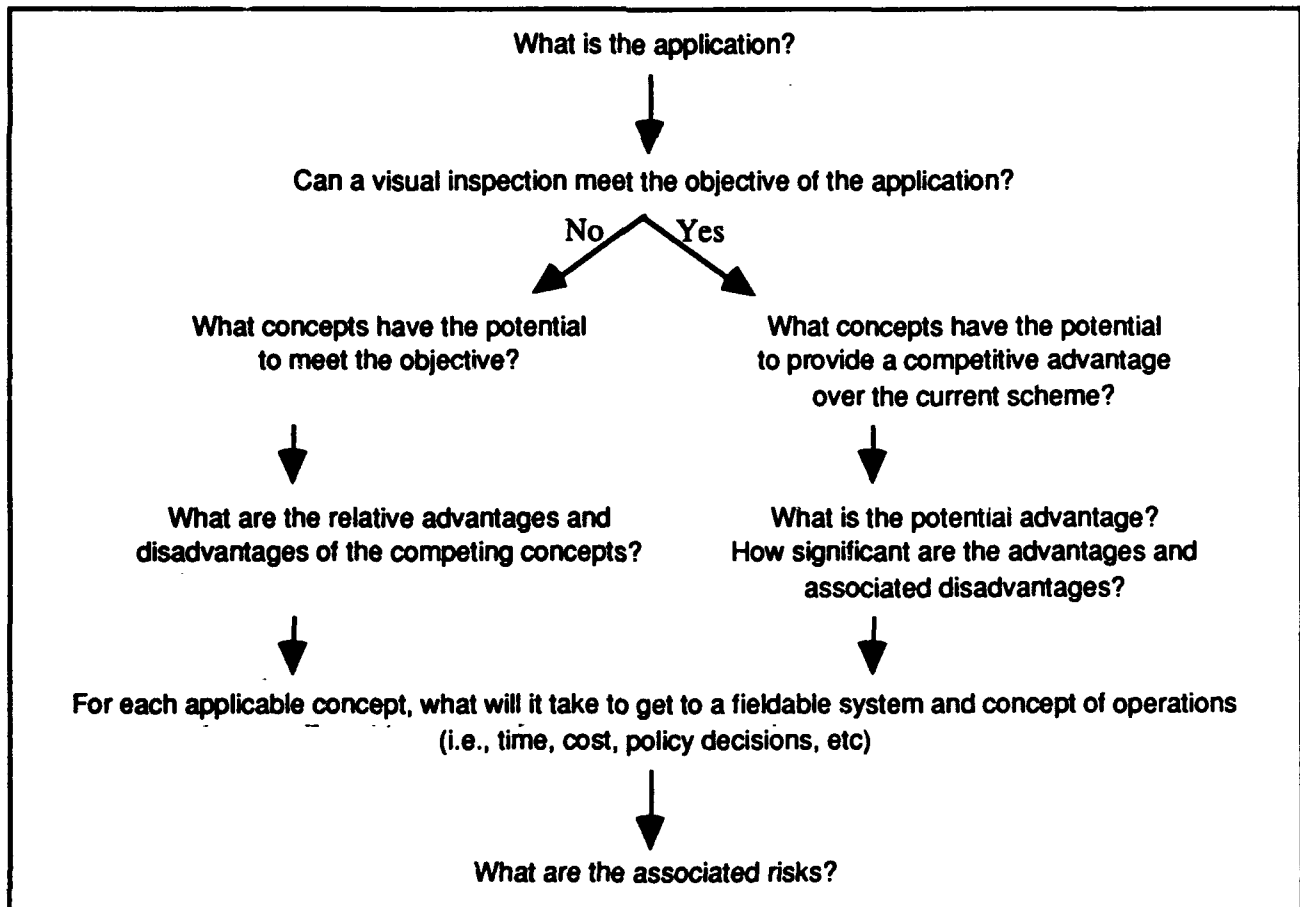


Figure 6-1. RVOSI technology study decision tree.

Combining these objectives with configurations, we considered 12 applications in the decision-tree process. Table 6-1 gives the classes of technologies we identified as potential inspection techniques for each application. Although the objective of confirming downloading is maintained as a separate entry, we agreed that some form of RV counting would satisfy this objective.

We also agreed early in the decision-tree process that all of the objectives, except for counting of nuclear warheads, could be accomplished using some adaptation of the START visual inspection protocol. Visual confirmation of bus changes would be very difficult to negotiate, but this objective became less critical as START II was proposed. The objective we consider most critical with START II is the counting of nuclear warheads. Proposed deep reductions in arsenals, along with missiles designed with significantly more throw weight than START II warhead allocations will allow, raise additional spoofing possibilities.

For those applications that can be accomplished using visual inspections, we observe that technologies offer no obvious advantages. In general, technologies require more gear, including detectors, a personal computer, and a power supply. As discussed previously, costs are dominated by the requirement for on-site inspectors and related preparation costs in both the FSU and the U.S. Operationally, end-on inspection technologies may have some advantage. The biggest advantage would be for the Peacekeeper configuration, which will be eliminated with the ratification of START II.

Only passive radiation-detection technologies can unambiguously verify the number of nuclear warheads. We could not develop any scenario for a radiation source of equivalent signature to indicate the presence of a warhead, except for a warhead. Gravity techniques may qualify for warhead counting if the presence of dense material is accepted by policy makers as an adequate indication of warhead presence. However, we could imagine the presence of penetration aids (PEN-AIDS) or other dense material concentrations, desirable for the fielding nation, which would give an incorrect warhead count.

Table 6-1. Decision-tree analysis matrix applicability of technologies to objectives.

Objective Configuration	Number of RVs ($<$ or \approx)	Number of nuclear warheads ($<$ or \approx)	Confirm downloading	Confirm bus changes
Silo-based	Visual Passive radiation Active radiation Acoustic Gravity gradiometry	Passive radiation	Visual Passive radiation Active radiation Acoustic Gravity gradiometry	Visual Radiography Acoustic
Mobile	Visual Passive radiation Active radiation Acoustic Gravity gradiometry	Passive radiation	Visual Passive radiation Active radiation Acoustic Gravity gradiometry	Visual Active radiation (Radiography) Acoustic
Sub-launched	Visual Passive radiation Active radiation Acoustic Gravity gradiometry	Passive radiation	Visual Passive radiation Active radiation Acoustic Gravity gradiometry	Visual Active radiation (Radiography) Acoustic

Our conclusions about the applicability of various technologies to the considered missile configurations focused on potential access problems. In order for a technology to provide an advantage over a visual inspection, the missile shroud must be able to remain in place. For the technology to provide the greatest advantage, the missile and front section must be able to remain in the launcher. Mobile missiles offer more options regarding access, so we focused on the more difficult problem of sub-launched and silo-based missiles. The many questions raised during team discussions about the potential ability of technologies to accurately count RVs/warheads for specific Russian missile configurations convinced us that computer modeling would be necessary to assess technology applicability to the RVOSI task.

As a result of the decision-tree process, we agreed on the following desirable characteristics for selecting a technology for advanced development.

The technology

- provides better inspection capability or inspection confidence than visual inspection.
- allows reduced operational impact by allowing the missile front end and shroud to remain in place.
- minimizes intrusiveness.
- minimizes equipment requirements and inspector burden.

Based on these characteristics, we eliminated several technologies and ranked the remaining technologies. Note that the top six technologies are all passive radiation-detection technologies, reinforcing our assessment that the capability to count nuclear warheads will become increasingly desirable. At this time, we judged active radiation techniques to be unnecessarily intrusive without providing additional capabilities. We omitted the elephant gun concept from the ranking because it provides no clear advantage over more developed technologies at this time. FATS was also eliminated because we judged that design changes could not simplify it enough that the inspector's burden would be acceptable. The following ranking is based on current best judgment; it could change as research and development progresses.

- GRIS
- Circumferential gamma-ray scanning (e.g., PGS and RAPID)
- Circumferential neutron scanning (e.g., PNS and RAPID)
- COSL
- HgI₂ camera
- Compton telescope
- Gravity gradiometry
- Acoustic techniques

GRIS is highly ranked because it is the most mature, end-on radiation-detection technique applicable to mobile, silo-based, and submarine-based missiles in their operational configurations. However, we are concerned about the reliability of GRIS since some of the data taken at FEW AFB for the

Peacekeeper configuration were ambiguous. With ambiguous results, it is also difficult to judge how well GRIS would work on Russian SLBM/warheads, considering their very different configurations. Some members of our team attended an in-depth review of GRIS at LLNL in November 1992. A review of the system and some concerns regarding characterization of the GRIS instrument are reported in Appendix B. When characterization of the GRIS camera is completed, we can reassess the reliability of the system.

Circumferential gamma-ray scanning ranked second because this mature radiation-detection technique gives the best results of any of the techniques reviewed, when used in configurations where the counting geometry is favorable (that is, with the detector counting plane in or near the plane of the warheads). However, the physical constraints of missile placement within the launch tube may prevent the use of this technique in an operationally favorable counting geometry with the missile, front section, and ascent shroud in place. If the missile front section must be removed for adequate access, this technique can be applied with the shroud in place. We were unable to judge the applicability of this technique to Russian silo-based and sub-launched configurations. The RAPID version of circumferential gamma-ray scanning has been demonstrated and has worked well, but other versions of this general technique could do the same job.

Circumferential neutron scanning is less reliable than circumferential gamma-ray scanning in the number of warheads. As demonstrated in the Peacekeeper experiments and because of neutron scattering concerns, it is unclear how applicable this system would be for Russian ICBM and SLBM configurations. However, since neutron counting techniques are perceived as less intrusive than gamma-ray techniques, we rank this technology fairly high. A number of circumferential neutron-detection techniques have been satisfactorily demonstrated.

COSL continued to raise operational questions among our team, but was ranked as shown because of its lightweight sensors and moderately successful performance in Peacekeeper testing. Alternatives to the current read-out process will probably be necessary for this technology to become truly competitive with those ranked above it.

The HgI_2 camera and Compton telescope are possible alternatives to GRIS. Because they are less mature and unproven against an actual missile configuration, they were ranked the lowest of the passive radiation-detection techniques. With the successful completion of a Peacekeeper or MMIII inspection, either of these technologies would rank directly after GRIS because of their ability to perform end-on inspections. The HgI_2 camera is ranked higher than the Compton telescope because it is more mature, although the Compton telescope has the potential for 3-D imaging. This 3-D capability may be very important for inspection of some Russian systems in their launchers.

We included gravity gradiometry in the ranking because this signature could possibly become acceptable for warhead detection. High cost and front-end access requirements are concerns for this class of technology. Proof of performance in a realistic RVOSI configuration is required before we can further assess this technology.

Acoustic techniques were ranked lowest because of continuing concerns about their ability to provide unique signatures. However, these technologies potentially are very compact, lightweight, and inexpensive. We were reluctant to totally omit these technologies until a definitive confidence test is performed. Since this technology cannot provide a warhead count, it has the lowest priority for further investigation.

In summary, the decision-tree process was designed to link the technology evaluations with specific missile system configuration applications. The process also took into account that different inspection objectives might provide different motivations for adopting a technology solution to the RVOSI task. The decision-tree process was never taken to its full conclusion, because many questions raised were not specific to an inspection system. However, the decision-tree process was a primary instrument for formulating our research recommendations.

SECTION 7

RESEARCH AND DEVELOPMENT RECOMMENDATIONS

In this section, we recommend research and development activities for DNA to consider in planning future investments in RVOSI technology. These range from detailed studies resulting in tools that can help DNA to better evaluate technologies, to advanced development issues that must be addressed before a specific technology can be qualified for treaty verification. Although many of these issues apply to all of the technologies studied, these recommendations focus on passive radiation-detection techniques because of their nuclear warhead counting ability and their added capability over visual inspections.

7.1 RECOMMENDATIONS FOR ANALYTIC MODELING STUDIES.

A great deal of research and development has been conducted on technologies for the RVOSI application. The two DOE-sponsored field demonstrations at FEW AFB were particularly valuable in providing us actual measurement data, essential to evaluating the applicability, capability, and maturity of passive radiation-detection techniques for performing the RVOSI function for an actual missile system (the Peacekeeper) to be inspected under the terms of START. The Peacekeeper was selected for these and other demonstrations since it was the most challenging U.S. configuration to inspect by RVOSI technology methods, and because the greatest benefits of such methods were expected to be achieved on the Peacekeeper system. However, neither this nor any U.S. system is representative of many Russian systems (in particular, the Russian SLBMs), and data collected for the Peacekeeper cannot be readily extrapolated to predict whether these RVOSI technologies would be successful when applied to Russian systems. Consequently, there are substantial uncertainties regarding the use of RVOSI technologies for inspection of Russian systems, which is the principal focus of this study.

As a result of these uncertainties, we recommend that a comprehensive analytic modeling effort be undertaken to provide the tools needed to evaluate the applicability of technologies to configurations that will need to be inspected. Since passive radiation technologies offer the unique capability of counting nuclear warheads, we recommend Monte Carlo simulation of radiation transport in representative missile systems. These simulations should be aimed at providing a tool to determine tradeoffs between neutron and gamma-ray detection methods, evaluating these methods for their adequacy for inspecting Russian systems, and examining spoofing scenarios associated with downloading of existing missile systems. An additional motivation for this type of study is the possible proposal of a passive neutron detection system by Russian scientists. Our team was made aware of the development of neutron detection equipment at Arzamas-16 for mobile missile systems. This raised serious questions with our team about whether this type of system could give sufficient spatial resolution of warheads to verify treaty requirements. Radiation-transport-modeling should provide sufficient information on the neutron radiation pattern to allow evaluation of the adequacy of this type of system.

For a baseline calculation, we considered suggestions for modeling a U.S. system that could be compared with experimental data. The initial recommendation was to model the Peacekeeper configuration, since a significant body of experimental data has been collected in DOE-sponsored testing at FEW AFB. Alternatively, the three-RV MMIII configuration could be modeled. This

alternative would require some sort of experimental verification, but would probably be more easily modified for modeling Russian and SLBM systems. A third option would be to model a U.S. SLBM, which like the MMIII, would require experimental verification. Since the team felt an SLBM was unlikely to be available for experimental verification, the MMIII was viewed as the preferred option for baseline modeling.

After a baseline model is developed, a series of parametric studies that introduce features of Russian systems should be pursued to evaluate how intervening materials (e.g., booster motors or fuel tanks) would affect the radiation pattern that an end-on instrument or a circumferential instrument would measure. Various spacings between warheads should be modeled to provide information on what instrument spatial resolution would be required to reliably count warheads. Shielding schemes and spoofing scenarios can also be modeled. Monte Carlo radiation transport codes exist in sufficiently developed forms that this type of modeling should not require code development and should be a cost-effective method to explore a wide variety of variables in the RVOSI problem.

Should gravity or acoustic techniques be adopted for reasons other than those identified by this study, structural modeling of missile systems may be desirable to develop characteristics that these inspection technologies would detect. The level of design detail required to accurately predict these characteristics will make this type of calculation very difficult to perform. We were divided on the value of this type of analysis, but we continue to strongly endorse radiation transport analysis as our top recommendation for further research regarding RVOSI technologies.

7.2 RECOMMENDATIONS FOR ADDITIONAL EXPERIMENTAL STUDIES.

Additional experimental work in support of the calculational effort may be required. We particularly recognize that, at this time, the MMIII missile system still exists in a three-RV configuration, but it is in the process of being de-MIRVed to a one-RV configuration. Since the team views the former configuration as more representative of future U.S. and Russian MIRVed SLBMs under START II than the Peacekeeper configuration previously explored, we recommend that a set of tests similar to the FEW tests be conducted against the MMIII configuration. Since the three-RV MMIII configuration will only be fielded for a limited time, these experiments need to be scheduled soon.

The team recommends testing one or two end-on imaging techniques, such as GRIS and the HgI₂ camera. Testing of GRIS would help to assess the confidence in this system, which was previously tested against the Peacekeeper. Testing of the HgI₂ camera would help to assess the maturity of this system and its competitiveness with GRIS. If the Compton telescope exists in a sufficiently mature form, it would provide an interesting third alternative. We also recommend testing a circumferential scanning technique such as RAPID, operated in a modified configuration at a high angle of observation, which would be more of an end-on inspection technique. This test, in combination with the recommended calculations, will help DNA to evaluate how important access will be for Russian systems. If instrument testing were carried out at an MMIII site, an additional test of COSL would fill out the suite of our preferred radiation-detection technologies.

This study has focused on "stand-alone" technologies that could complete the RVOSI task with minimal inspector interaction—that is, technologies that could be automated to a "red light/green light" indicator. As we considered potential spoofing scenarios and methods for increasing confidence, we discussed technology inspection concepts other than stand-alone technologies. These concepts included augmenting visual inspection with simple radiation-detection equipment, such as a

Geiger-Mueller counter, or the use of neutron or gamma-ray detectors in "passport" mode. The passport mode is exemplified by the INF inspection procedures, where a comprehensive set of neutron measurements was collected as a benchmark. At the time of inspection, a specified set of measurements is taken and compared to the comprehensive baseline to determine whether treaty conditions are met. These alternate inspection methods appear less desirable to our team from a technological and confidence standpoint. However, since they may introduce negotiability advantages that stand-alone technologies do not, we submit them as options to the technologies more fully discussed in this report.

Other experimental studies that we identified for future consideration include an SLBM configuration test. This type of experiment would be extremely valuable, especially in light of the continued use of MIRVed SLBMs after START II. In fact, SLBM experiments might have been our first priority in this category if not for the limited time frame of MMIII availability, and our perception that the Navy is unlikely to permit measurement experiments on an SLBM in its launch tube.

Development of some mock Russian missile configurations may be needed to verify calculational assumptions at some time in the future, but MMIII baselining of calculations should provide adequate data for numerous trade-offs to be explored without another major field test effort.

7.3 RESEARCH INTO DATA PROCESSING ISSUES.

Two assumptions made in the decision-tree process were (1) that some of the intrusiveness concerns associated with the use of RVOSI technologies could be remedied by appropriate data processing and (2) that an actual count of RVs or warheads could be converted to a "not more than X" readout. We understood in making these assumptions that several barriers, both technical and political, must be overcome for these assumptions to be fully realized. Consequently, we encourage DNA to invest in studies to further investigate the development of, proof of, and confidence building in concepts that allow this kind of processing. Two major areas that we think should be addressed are methods to mask excess data collected by an inspection instrument and techniques to ensure that sensitive data are neither stored nor transmitted by that instrument. Both of these areas depend on robust data processing algorithms, combined with security protocols that assure the inspected party that sensitive information is protected, while assuring the inspecting party that the inspection is a valid reflection of the existing missile/warhead configuration. These data processing algorithms and security protocols can be developed, to a large extent, independently from any specific RVOSI signature. The Controlled Intrusiveness Verification Technology (CIVET) program, currently underway at Brookhaven National Laboratory, is an example of the type of hardware, software, and protocol combination that may be required to solve intrusiveness problems with RVOSI technologies.

Both of these areas of investigation will depend on the ability to develop automatic signature recognition algorithms, so that inspectors do not have to see and interpret the data collected by the inspection instrument. Research to date has been focused on developing an RVOSI signature an inspector could visually identify. To protect sensitive data and to ease inspector burden, we may need a robust automatic signature recognition algorithm. This research will be more signature dependent than the other data processing studies identified above, although it can draw from a wide body of statistical methods developed for automatic target recognition applications.

Research into these data processing issues along with analytic modeling will be essential before any technology should be recommended for advanced development.

7.4 INSPECTION SYSTEM DEFINITION FOR ADVANCED DEVELOPMENT.

As we studied the RVOSI technologies, we found that uncertainties in inspection system requirements often prohibited us from making adequate evaluations. Before any system is further developed, policy decisions need to be made regarding a number of issues that affect the engineering details of many systems, and which may eliminate others. Technical evaluation of the techniques we studied can identify trade-offs between technologies, but we did not feel qualified to eliminate most technologies because of, for example, unacceptable inspector burden. We could not judge the acceptability of special-purpose vehicles over man-portable equipment. All of the technologies ranked in the decision-tree process can conceivably be engineered to be packaged in several man-portable or two-man-portable cases. In addition to portable equipment, a support structure may be needed, to be provided by the host nation.

Our team discussed and speculated at length about what degree of access would be permitted to inspectors and/or instruments for missiles in silos or launch tubes. As with inspector burden, we tried to identify trade-offs between technologies regarding access requirements, and used this factor to rank the technologies. We were unprepared to make firm statements regarding access requirements, although we assumed that access would be fairly restrictive, especially on Russian systems. The modeling studies recommended previously should help to clarify the access that various instruments require to function properly.

The team also discussed additional constraints and challenges that de-MIRVing and other deep cuts in arsenals might place on the RVOSI task. Spoofing scenarios associated with these cuts and missiles with excess throw weight were a significant concern. Full evaluation of the implications of de-MIRVing will become more clear as START II is ratified and as proposals for future force structures become more defined. RVOSI requirements will be more clear at that time and the applicability of technologies for future tasks should be revisited.

We did identify one inspection system feature that design efforts could focus on at this time. If an end-on inspection technology (either end-on imaging or modified circumferential scanning) appears a likely solution for the RVOSI task, a generic instrument support structure for both silos and submarine tubes will be required. This type of structure could be substantially designed before a specific inspection system is selected. We would expect this type of fixture to reside in the host nation for inspections.

7.5 CONFIDENCE STUDIES OF SYSTEMS IN ADVANCED DEVELOPMENT.

Although confidence in the ability of a technology to accurately complete an inspection was our most important evaluation factor, we found that no technology had been tested adequately for us to make a quantitative evaluation of reliability or spoof resistance. Studies, required for any system that advances toward a fieldable system, will include a statistical analysis of the potential for false positives or anomalous results. Technologies at present have been tested against a realistic missile configuration a limited number of times. More data will be required to fully evaluate potential sources of error. The analytic studies we have recommended will provide a body of information from which to draw to guide these studies, as well as spoofing studies to evaluate the potential for treaty violations not being detected (false negatives). As with previous treaty verification protocols, we would expect any RVOSI technology to be confronted with a serious Red-Team challenge before it would be approved.

As indicated in our discussion of experiment recommendations, testing of RVOSI techniques against a Russian configuration or a mock-up resembling a Russian system may become desirable in the future. The success of the analytic modeling effort will, to a large extent, determine the level of confidence building that must be pursued. Finally, as confidence levels in a developing technology are more fully assessed, anomaly resolution procedures can be developed. These procedures might include an inspection using a second technology or a backup visual inspection protocol.

SECTION 8 CONCLUSIONS

Although the visual-inspection protocols developed under START for RVOSI are personnel intensive, intrusive, and operationally disruptive, we found no clear indication that use of a technology for the inspection would eliminate any of these problems or reduce costs. The potential advantages of RVOSI technologies are limited to passive radiation-detection technologies, which provide the additional inspection capability of counting nuclear warheads rather than RV-size shapes. This additional capability enhances confidence in the inspection result and would eliminate certain spoofing possibilities, which the deep cuts in nuclear arsenals specified in START II make potentially possible. Gravity gradiometry and acoustic technologies may become viable for RVOSI applications in the long term, but are significantly less attractive than the radiation-detection technologies because they provide no enhanced inspection capability.

Although very valuable experimental work has been conducted in developing passive radiation RVOSI technologies (chiefly the DOE-sponsored field demonstrations at the FEW AFB), we recommend that a comprehensive analytic model be developed to aid in trade-off analyses between various radiation-detection technologies, and to build confidence in the ability of these technologies to verify treaty compliance for a wide variety of missile configurations. These studies will support the main goal that we identified for the near-term DNA RVOSI technology development program: to better define inspection system access and spatial resolution requirements, to better evaluate their applicability to Russian configurations, and to evaluate spoofing scenarios. Some experimental verification of the calculational work will be required. We recommend the use of the MMIII missile system for this verification before de-MIRVing occurs. Other experiments could be substituted for this if the calculational effort is correspondingly modified.

In the longer term, several issues will require attention before advanced development of any system should proceed. Chief among these is the issue of data processing or other techniques to reduce intrusiveness concerns. We anticipate that automatic signature recognition algorithms will be a component of this issue, which will also reduce inspector burden by automating the data collection process. Further definition of inspection system requirements should be developed if a technology is selected for advanced development. Areas we identified as particularly needing further definition include inspector burden and instrument access to missile systems and systems expected to exist after deep arsenal cuts. Finally, any system that is further developed will require additional confidence-building studies to resolve questions about the potential for false positive, false negative, and anomalous readings, as well as to further evaluate spoofing possibilities.

The RVOSI Technology Study identified no technology that readily solves the problems associated with START-prescribed visual-inspection protocols. Any commitment to hardware development should be preceded by, at least, modeling studies of the type discussed above. Technology solutions for the RVOSI task can be re-evaluated in the future if other technologies are developed which introduce new capabilities. Technology development for RVOSI appears to be primarily of interest if the technology provides enhanced confidence or additional capability over visual inspections, particularly if it becomes desirable to determine the number of nuclear warheads on board a missile.

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APPENDIX A
EVALUATION MATRIX AND PRELIMINARY TECHNOLOGY EVALUATIONS

The first step in Reentry Vehicle On-Site Inspection (RVOSI) technology evaluation was the development of an evaluation matrix and preliminary evaluations by individual team members. To provide more complete information than contained in the summaries in this report, this appendix contains the evaluation matrix from which all reviewers worked, as well as preliminary evaluations. This appendix includes:

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**RVOSI TECHNOLOGY STUDY
EVALUATION MATRIX
Revised -- 21 May 1992**

Technologies	Inspection Objectives				
			Evaluation Factors (Findings Maturity Cost)		

INSPECTION OBJECTIVES

Each technology will be evaluated against its ability to do the following missions.

- Determine that there are no more than X reentry vehicles (START criterion)
- Determine the number of reentry vehicles
- Detect the presence of nuclear warheads
- Determine that there are no more than X nuclear warheads
- Determine the number of warheads present
- Distinguish between nuclear warheads and reentry vehicles
- Confirm irreversibility of downloading/Confirm bus changes

TECHNOLOGIES

The following technologies will be studied. Lead investigators are responsible for locating documentation and points of contact for these technologies by 24 June 1992. Organizations which we believe have information on these technologies are identified, although inquiries need not be limited to these organizations. Any gaps in information which we will need to investigate further before evaluation can be completed should be identified at this time.

Passive Radiation Detection Techniques

Bill Johnson, Dave Gordon, Lead Investigators

Circumferential Neutron Scanning

PNS -- LANL

RAPID -- SNL

COSL -- PNL

SRS (with X-ray fluorescence) -- SRS

Directional Neutron Detector -- PNL

Circumferential Gamma Scanning

PGS -- LANL

RAPID -- SNL

End-on imaging

URA -- GRIS -- LLNL

Zone plate -- HgI2 camera -- EG&G

Compton Telescope -- ACTEL -- ISST

Fourier Transform Camera -- Many developers

WINKLER -- Lockheed (not applicable to RVOSI)

"Elephant gun" -- LANL

Coincidence counting

FATS -- INEL

TECHNOLOGIES, CONT.

Active Radiation Detection Techniques

Gary Phillips, Dave Gordon, Lead Investigators

Transmission Scanning

Hodoscope -- ANL

Radiography survey -- Raytheon

Backscatter/Fluorescence

SRS/BMO combined method (grew from LLNL technology)

Infrared

Mary Abe, Lead Investigator

US Navy R&D San Diego (formerly NOSC)

Guy Mastney

Mike O'Connell, DOE

How useful was Army experiment done by NOSC?

Acoustic

Cos DiMaggio, Lead Investigator

ARS -- LANL

LFM -- SPC

FRM -- LLNL

Gravimetry

Cos DiMaggio, Lead Investigator

Gravity Gradiometry -- MITRE, SPC

Visual Methods

Joe Halpin, Lead Investigator

EVALUATION FACTORS

The Study Team's recommendations to DNA for an RVOSI technology investment strategy will be based on five evaluation factors detailed below. In considering each of the five evaluation factors the following parameters should be considered

- Export control policy at this time
- Technology Maturity
 - What is the state-of-the-art?
 - Has proof of principle been completed?
 - Is a fieldable unit available?
- Scenario dependence of the technology for
 - Silo based missiles
 - Missiles on mobile launchers
 - Sub-launched missiles

Evaluation Factor 1. High confidence in the ability to do the inspection

- Reliability -- 1 measurement = 1 correct answer
 - sources of error and can they be overcome
 - requirement of baseline information
- Spoof resistance
 - signature spoofing
 - equipment spoofing
 - protocol spoofing
 - what is the desirability of doing this spoof

Evaluation Factor 2. Cost

Jeff Grotte, Julia Klare, Lead Investigators

- Life cycle costs
- System cost and complexity
- Cost/manhours for total inspection operation
- Development cost of special purpose vehicles or equipment

Evaluation Factor 3. Intrusiveness

- Information gained beyond that required for inspection
 - Does inspector have to be physically present?
 - warhead size, shape, materials, or age
 - missile launcher details, PEN AIDS
 - image
 - intelligence data that can be obtained
- Can potentially intrusive info be masked and inspection still be completed

Evaluation Factor 4. Operational impact

- System downtime
- Operational requirements
 - Time for data collection
 - Environmental protection of missile
 - Can physical barriers to the silo be maintained?
 - What can be done to mitigate the impact?

Evaluation Factor 5. Inspector's burden

This factor will require OSIA review

- Weight and volume
 - Man portable preferred
- Ease of use
 - Calibration
 - Simplicity of set up and operation
- Safety
- Special requirements
 - Power source
 - Special materials
 - External calibration source
 - Special purpose vehicle
- Maintainability
 - Operable in real environments
 - Durability/ruggedness

EVALUATION OF VISUAL METHODS
Evaluator: Joseph Halpin
1 July 1992

INSPECTION OBJECTIVES

1. Determine that there are no more than X reentry vehicles.
Yes. This method has been baselined to the satisfaction of OSIA.
2. Determine the number of reentry vehicles.
No. When stiff or hard covers are used the inspectors cannot determine the exact number of reentry vehicles.
3. Detect the presence of nuclear warheads.
No.
4. Determine the number of nuclear warheads.
No.
5. Distinguish between nuclear warheads and reentry vehicles.
No.
6. Confirm the irreversibility of downloading/confirm bus changes.
No. Because drapes are used to obscure the details of the bus, it would be impossible to detect bus changes unless the drapes were removed.

EVALUATION FACTORS

1. High confidence in the ability to do the inspection.

1.1 Reliability

The visual technique, using covers on the reentry vehicles, is highly reliable. The only possible cause of concern is that an unusually small reentry vehicle might be placed under the drapes which are used to cover the bus. This is unlikely since it would have to be a very small body, it would have to displace something, and there is a baseline inspection where we are given a chance to be satisfied with understanding all the bumps. Tactically it is not clear that there would be enough benefit to include a very small reentry vehicle and risk detection. Therefore, I conclude that the visual inspection technique is highly reliable.

1.2 Spoof Resistance

The visual inspection techniques, as approved, appear to be a high confidence approach with little risk of mischievous behavior. For example, if the inspectors are concerned about an unusual shape the inspected party must convince the inspectors that the unusual

shape is not a warhead. (A simple technique is to measure the gamma radiation level; the inspectors should be prepared to make this measurement, if necessary. However, the inspectors role is only to challenge the inspected party, it is up to the inspected party to do what they deem necessary to convince the inspectors that the challenged object is not a warhead). Therefore, I conclude that one is not able to conceal a warhead beyond the treaty allowed number.

2. Cost

At this time the non-recurring costs of the visual inspection equipment is a sunk cost; this includes the covers, the inspection/containment enclosures, lifting mechanisms and the support vehicles. The estimated cost of the hard covers, used in the inspection of the submarines, is about 300k; this cost includes the design of the covers and the procurement of enough fixtures to have one at each submarine base. I do not know the cost of the soft covers used in the inspection of the silo-based missiles. There is no or little annual maintenance cost for either the hard or soft covers.

For more specific information on the procedures and cost to inspect U.S. equipment--for the AF vehicles call LtCol Dick Rock, AF/XOXXI 703-697-5622; the Navy vehicles Pete Gratton, OASN RDA 703-695-3942. There is a DNA contract report, Technical and Cost Considerations for Reentry Vehicle On-Site Inspections, August 1989, DNA001-88-C-0046(S), which contains a cost analysis for the Peacekeeper and the Minuteman III RVOSI. This analysis was performed by RDA. The results are classified.

The cost of the hardware for the visual RVOSI of the Former Soviet Union (FSU) reentry vehicles is a cost that is borne by the FSU. This cost includes the covers and the associated hardware for installation of the covers.

3. Intrusiveness

3.1 Information gained beyond that required for inspection

The risk for intrusiveness is moderate; the reason for this level is that the inspectors must be near the missile (even for those cases where the front end is removed from the missile) to ensure that there is no hidden reentry vehicle. By being near the missile, the missile silo/tube, or the missile front end, there is the chance that an inspector could be carrying an electromagnetic emitter or detector to either create problems in electronic systems or to pick up signals that are not necessary for the inspection. Being close to the missile silo/tube. gives the inspectors the opportunity to see other than treaty-limited items. The other concern is for the opportunity for something to be dropped into the silo or tube. Outside of these concerns there appears to be no other significant risks in the visual RVOSI approach.

The Former Soviet Union (FSU) does not appear to be as concerned about this type of intrusiveness. However, if the US decides to use the special drapes (see 3.2), it is possible that

the FSU will request the opportunity to purchase such drapes for their systems.

3.2 Can potentially intrusive information be masked and inspection still be completed?

For the above concerns there has been developed a drape or cover which provides visual and electromagnetic shielding. This drape appears to be adequate to protect our systems.

4. Operational Impact

4.1 System downtime

In the case of the Minuteman II missile, the only method which could be shorter is a technique which allows the inspection without removing the hatch or silo cover. For the MM III a technique which avoided the removal of the nose tip, but which did not take any longer to perform, has the potential to save operational downtime. The estimated downtime for the Minuteman III system, based on the demonstration with the FSU inspection team, is 12 hours.

In the case of the Peacekeeper, these are more complicated RVOSI procedures, requiring the removal of the front end with all the attendant complications and a much longer setup and reconstitution time. Here the total downtime is about 3 days. This procedure is similar to that demonstrated for the FSU SS-18.

For the RVOSI of submarines two techniques were demonstrated; in one approach the missile remained in the launch tube, in the other approach the missile front end was removed to a pier-side handling facility. It is only this latter approach which the FSU demonstrated. These procedures take the submarine out of service for about 24 hours. In addition, it could take from 6 hours to several days to get a designated submarine into a submarine base.

4.2 Operational Requirements

In each of these cases the actual RVOSI data collection time is on the order of 15 minutes; this time is insignificant compared to the time to prepare the base and the systems, and to reconstitute the systems after the inspection. Since the submarines are under cover when the missiles or front ends are unloaded, environmental concerns are not a big factor. For the Minuteman and Peacekeeper missiles there is more concern for the environment; I would think that the Air Force would like to avoid temperature extremes and precipitation. Here is an example of where the FSU inspectors, by their choice of missile location and time of year, could make things more difficult for us.

While there is no reason for the FSU inspectors to go below surface/deck level, they have the opportunity to stand at the edge of the silo/tube.

Those RVOSI approaches which require the removal of the nose tip, shroud or the missile front end require special vehicles or facilities. These vehicles or facilities are supplied by the inspected country and these equipments were in existence before the requirement for RVOSI, that is, they are not special purpose equipment, developed specially for RVOSI.

5. Inspector's Burden

5.1 Weight and volume

The issue of man portability is a concern for the technique used in the inspection of the US submarines. Here, hard covers are used; these covers require the use of a crane. I believe they weigh about 800 lbs. For this and other reasons these covers are kept in the US. These covers are available at every major submarine base. It is the US responsibility to store and transport these covers to the inspection facility, as required. This means that if these fixtures are not stored at the inspection facility, a vehicle big enough to carry the fixture must be provided along with a crane to load and unload the fixture. Therefore, for the US escorts of the FSU inspectors, there is a weight and volume burden in the inspection of the US submarine reentry vehicles.

The covers used for the US, silo-based systems are soft covers, which I believe do not have a special weight or volume concern.

The covers used for the inspection of the FSU reentry vehicles are described as "stiff, soft covers." Since these covers are the property of the FSU, the FSU inspectors would be in charge of transporting and storing these covers. Therefore, for the inspection of the FSU reentry vehicles, there is no weight or volume burden for the US inspectors.

5.2 Ease of use

Some minimal training is required for US personnel to apply the soft covers for the silo-based missiles; more care and training is required for the hard covers used in the inspection of the US submarines. For all but the Minuteman II missile, there is some disassembly of the missile required.

The ease-of-use issue is not a concern in the inspection of the FSU systems since we would expect that they would perform all of the operations associated with their missile systems.

There are no calibration requirements for the covers. The only certification required is to visually inspect the covers before they are applied to the "reentry vehicles."

5.3 Safety

The safety concerns are for the weight of the hard covers and the process of dismantling the missile front ends, shrouds or nose tips, where these apply. However, when such covers are being used on FSU systems, they will be in charge of the missile disassembly and the placement of the covers. In this case only the "ordinary" concerns of working around open silos and radiation sources apply.

The other safety concern during the visual inspection of the FSU reentry vehicles is for the radiation exposure of our personnel. During the demonstration in the FSU, our inspectors were required to wear rubber suits to eliminate the radiation contamination around the submarine reentry vehicles. When proper techniques are used, the radiation exposure to our personnel is minimized. An alternate technique, which avoids our personnel being this close to the exposed FSU reentry vehicles, would eliminate this concern/hassle.

5.4 Special requirements

Special purpose vehicles, enclosures, cranes and/or fixtures are used in the visual inspection of the submarines, the Minuteman III, and the Peacekeeper. The Peacekeeper inspection requires 5 vehicles and a helicopter. The submarine-facility-inspection enclosure, is a special purpose fixture, but has other uses.

5.5 Maintainability

The covers for the visual inspection technique are rugged and require almost no maintenance.

5.6 Environmental concerns

The environmental concerns for the visual inspection technique are for those cases where missile disassembly in all conditions is a requirement, e.g., for the Peacekeeper, and Minuteman III missiles. For these cases extreme temperatures and precipitation are concerns.

6. Other Factors

6.1 Export control

There are no special materials or devices in the visual inspection technique which are a concern for export control.

6.2 Technology maturity

Not an issue.

6.3 Scenario dependence

The application of the visual inspection technique has scenario dependencies; these are addressed above (see sections 4 and 5).

6.4 References

See section 2. Also for any information related to the demonstration of RVOSI and to the inspection techniques developed for use in the FSU, the POC is LTC Robert Yablonski, OSIA, 703-742-4589.

VISUAL INSPECTION TECHNIQUE

Discussion

The visual inspection technique is to simply cover the reentry vehicles with a cloth or hard cover, then to have the inspectors within 5 meters for 15 minutes to count the reentry vehicles. In the technique demonstrated for the inspection of the US systems, soft covers were used for the inspection of silo-based systems (Minuteman III, and Peacekeeper) and molded fiberglass covers, assembled in a frame, were used for the submarine systems. All of the hardware for the visual inspections of the US missiles exists, it is a sunk cost.

The covers for the submarine application are formed enclosures, roughly the shape of the reentry vehicles. They are open on the large end and suspended on the other end via a ring and frame. The weight of the structure is estimated at 800 lbs; it must be moved and placed with the use of a crane.

The RVOSI of the US missiles differ somewhat among the systems. The Minuteman II RVOSI only requires that the silo hatch be moved to expose the missile. The inspection is to determine that there is a single missile of that type in the silo.

The Minuteman III missile RVOSI requires the removal of the missile nose tip and the placement of soft covers over the reentry vehicles. Other details of the bus are obscured by a cloth drape. This procedure requires the use of special vehicles and added security; it is estimated that the system downtime for this process is 12 hours.

The Peacekeeper missile RVOSI requires the removal of the missile front end and the transport of the front end to a special-missile-handling facility where the reentry vehicles are covered with the soft covers and the bus is covered with a drape to obscure the details of the bus. Before the front end is transported to the missile-handling-facility, the inspectors are permitted to look into the silo to ensure that there are no hidden reentry vehicles. During this time the exposed end of the missile is draped to avoid revealing other than treaty-limited information. This entire procedure requires 5 vehicles, a helicopter and about 30 people. The estimated system downtime is about 3 days.

The RVOSI for submarines can be done in either of two ways; the reentry vehicles can be inspected while in the launch tube or they can be inspected after the missile has been removed from the launch tube. In either case a special purpose facility (not only used for RVOSI) is used to remove the missile nose fairing or the entire missile. The hard cover is inspected before it is used to cover the reentry vehicles and cloth drape is used to hide other-than-treaty-limited information about the missile front end. This

procedure is estimated to cause the submarine to be out of service for about 24 hours. Additionally, the submarine will be out of service from the time it has been called into the submarine base until the time it takes to get back on station, but this factor is no different for any other RVOSI technique.

The visual RVOSI procedures for the missile systems of the Former Soviet Union (FSU) also vary by missile type. For the FSU submarines the approach that was demonstrated was to remove the missile front end, place it on the pier and to cover the reentry vehicles with starched, canvas covers. Our inspectors were on site about 8 hours for this process.

In the demonstration of a silo-based missile (the SS-18), the front section was removed and placed on a nearby helipad. Again the soft, stiff covers were used to cover the reentry vehicles and a drape covered the bus and other objects on the front end. This is a two stage missile front end; it was not separated for this demonstration. In spite of the fact that the two stages were not separated, our observers were convinced from the geometry of the platform and the dimensions of the reentry vehicles that there could be no hidden reentry vehicles. The total time that the observers were on site for this inspection was 10 hours.

There were no other FSU missile systems included in the demonstrations. It is assumed that the inspections for the mobile missiles will follow the pattern of removing the missile front end and covering the reentry vehicles with the soft, stiff covers. However, we know that the SS-11, a 3 warhead missile, which according to the Start Treaty is not allowed to have MIRV capability (page 17 of the Treaty) will not have an RVOSI inspection per se (Senate Committee on Foreign Relations Treaty Document 102-20, 25 November, 1991). The inspection will be to validate that the missile is an SS-11, there will be no count of the reentry vehicles (3) or independent validation of the lack of MIRV capability. Instead the reentry vehicle count and the MIRV-capability judgments are based on "national technical means".

CIRCUMFERENTIAL NEUTRON SCANNING (CNS)

Note: CNS subsumes the neutron parts of the RAPID technique (aimed at thermal neutrons) and the SRS system, as well as the PNS technique (fast neutrons). As with CGS, I have made an attempt to distinguish between in-principle characteristics of CNS and the three actual implementations.

INSPECTION OBJECTIVES

1. Determine that there are no more than X RVs.
No: technique looks only for neutron emitters (presumed to be plutonium-bearing nuclear warheads).
2. Determine the number of RVs.
No.
3. Detect the presence of nuclear warheads.
Yes, assuming the nuclear warheads contain plutonium. Detection of all-or-alloy warheads would probably be impossible.
4. Determine the number of warheads present.
Yes, assuming the warheads contain plutonium.
5. Distinguish between nuclear warheads and RVs.
As with CGS, this technique could tell whether a massive object found with some other technique (e.g. gravity gradiometry) contained plutonium (and hence a warhead), but cannot make such a differentiation by itself.
6. Confirm the irreversibility of downloading.
No.

EVALUATION FACTORS

Evaluation Factor 1: Reliability.

Reliability of neutron techniques is difficult to judge, because measurement of neutrons involves so many variables. There appears to be little doubt that the neutron part of RAPID succeeded in recognizing all 10 warheads present on the Peacekeeper missile where RAPID was demonstrated. PNS and SRS arrived at somewhat divergent conclusions regarding the detectability of the tenth (inner) warhead. Both RAPID and PNS worked well on a Minuteman-III-like mockup, and the SRS system would presumably do so as well. In the case of warheads close to an efficient neutron scatterer -- for example, rocket motor -- reliability not only has not yet been demonstrated, but is difficult to predict on the basis of calculations. More R&D is needed.

Because CGS relies on the detection of neutrons from ^{240}Pu (or possibly from (α, n) reactions associated with alpha decay), detection of all-or-alloy warheads with any of the CGS technologies

is problematic at best: it is most unlikely that the low levels of alpha activity displayed by ^{235}U or ^{238}U would produce enough neutrons to be detectable. Similarly, spoofs involving "Ivory" plutonium (plutonium very low in the isotope ^{240}Pu) are theoretically feasible, if an adversary has a supply of "Ivory" plutonium or can do isotope separation. The likelihood of either of these approaches is open to question. Spoofs involving shielding would be difficult to accomplish, because of the large quantities of hydrogenous material required.

Evaluation Factor 2: Cost.
Being examined by IDA.

Evaluation Factor 3: Intrusiveness.
Many of the same intrusiveness concerns exist for CNS as for CGS. Neutron dose rates at known locations from a known nuclear weapon are classified Confidential/Restricted Data. The dose rates can be concealed, in principle, by the electronics/computer used to operate the detector. The RAPID and SRS detectors have no spectroscopic capabilities, so no spectral information is available (and therefore must be concealed) with these systems. The PNS detector does have the capability for spectroscopy, but it could be discarded. Throw-away use of these systems, as noted for CGS, is problematic due to the potentially greater expense.

Evaluation Factor 4: Operational impact.
Many of the same general observations that were stated for CGS (emplacement in silo vs. use through silo door, etc.) apply for CNS as well. The RAPID demonstration on the PK was constrained in time by the neutron count rate, rather than gamma. All counts were done within 4 hours of startup. Counting time for PSN was considerably longer; in the 4 hours available for counting, not all hoped-for detector positions could be used. SRS describes count times for their neutron system as "Long(Hour(s))." As a general rule, CNS appears slightly more time-consuming to emplace in a given setting than CGS in the same setting, and might take two or three times as long for data acquisition.

Evaluation Factor 5: Inspector's burden
In CNS, the dominant contributor to the weight/volume of the material an inspector must carry is the detector itself, with volume being possibly a more significant factor than weight. (In contrast to CGS, the shielding material used to collimate the detector is low-density polyethylene.) The detector used in the PNS work at Warren weighed perhaps 100 pounds, the RAPID detector somewhat less. Lacking a known weight for the SRS neutron detector, a thumbnail estimate is that this system too would weigh roughly 100 pounds, possibly somewhat more. Modular design could allow the detector to be assembled from pieces weighing no more than a few tens of pounds each; this was actually done with the PNS detector and presumably could have been done with the others.

It also might be possible to reduce the total weight through careful optimization of the shielding material, but reductions below the 50-pound level (as a guess) would likely be achieved only at the expense of reduced detector size (hence longer count times) or poorer collimation (hence less reliability). It is possible that the RAPID detector is already smaller than it should be for efficient operation; a repeat of the Warren demonstration with RAPID, scheduled for this August, may address this.

The RAPID system requires, in principle, nothing more complex for data collection and display than simple rate meter. However, use of a rate meter poses problems involving intrusiveness. Operation with a microcomputer front end could address these problems while still leaving the system operable in a push button mode. PNS in its current form requires a computer for data collection and analysis, although it is probable that its developer will be funded this year to produce a stripped-down detector with less complex data-reduction requirements. The PNS detector in its current form also involves use of a large, cumbersome bundle of cables between detector and electronics, but the R&D effort is expected to reduce this bundle to more manageable size. The use of an anticoincidence counter in the SRS detector practically guarantees that electronics used in this system will be more complex than for RAPID, although again a properly designed front end should be able to make this complexity invisible to the operator.

No safety concerns are obvious with any of these systems. For some if not all systems, it would be desirable to have a small neutron source available for calibration and instrument checkout. Check-source-sized neutron sources pose no great safety concerns but do require special procedures for transportation, etc. Experience under the INF treaty has shown that these procedures can be dealt with successfully.

All systems as used at Warren required AC electrical power. It would certainly be possible to reduce the RAPID electronics to a battery-powered package, and may be possible to make similar reductions in the PNS and SRS packages; however, at least PNS is not currently in such an independent package.

The PNS detector is already quite rugged (it was designed for use aboard a satellite), while insufficient information exists on the ruggedness of the other systems. Both RAPID and the SRS system are based on ^3He tubes, which are routinely used in highly rugged apparatus in nuclear safeguards. Ruggedized electronics would obviously be essential for any final, fieldable system.

Evaluation Factor 6: Other.

Export control: No apparent problems, although with PNS in its current form, data reduction requires a relatively powerful computer; it might be necessary to make some compromises in the

speed of the data reduction to ensure that the computer used is exportable.

Technology maturity: Less than for CGS. All systems have been demonstrated against a PK, but more work is required to optimize the detector package.

Scenario dependence: Uncertain but possible substantial. The presence of a tractor motor might cause neutron techniques serious trouble because of scattering. R&D is needed to address this question.

CIRCUMFERENTIAL GAMMA SCANNING (CGS)

Note: The RAPID and PGS systems are the existing examples of circumferential gamma scanning. In the following discussions I attempt to draw a distinction between in-principle characteristics of the technique and those characteristics possessed specifically by RAPID and PGS in their current forms. It should be recognized that both RAPID and PGS were developed and used in response to taskings that were slightly different from those an actual on-site inspector would produce. In the more general, in-principle discussions I have attempted to identify places where these techniques might be modified if mandated by use in on-site inspections.

INSPECTION OBJECTIVES:

1. Determine that there are no more than X re-entry vehicles (RVs).
No; technique looks only for warheads.
2. Determine the number of RVs.
No.
3. Detect the presence of nuclear warheads.
Yes, provided they contain plutonium. All all-or-alloy warhead would be difficult to detect reliably.
4. Determine the number of nuclear warheads present.
Yes, provided they contain plutonium.
5. Distinguish between nuclear warheads and RVs.
??? What does this objective mean? In conjunction with some other technique for detecting massive objects (for example, gravity gradiometry), CGS could distinguish whether a particular massive object contains plutonium (and, presumably, is a weapon), but cannot make any such differentiation in isolation.
6. Confirm the irreversibility of downloading.

EVALUATION FACTORS

Evaluation Factor 1: Reliability.

Realistic demonstrations have shown that both approaches to CGS (RAPID, PGS) can reliably count the 10 warheads on a Peacekeeper missile and the 3 warheads on a Minuteman III missile. Neither system has been demonstrated against other weapons systems, but both can be expected to function reliably against systems of the same general geometry as either the PK or MMIII. In-principle limitations exist on the ability of CGS to count warheads not containing plutonium. Limitations may also exist on the reliability of CGS when the RVs are shielded from viewpoints at the side of the missile, for example by a tractor rocket motor.

Reliability of the technique in such a geometry must be assessed on a case-by-case basis.

In-principle spoofs of CGS exist, in the shape of artfully placed shielding between detector and radiation-emitting parts of the weapons system. The practical significance of such spoofs is unclear but probably low, owing to the undesirable effects shielding materials would have on weight, center of gravity, etc., of the weapons system. A detailed vulnerability analysis of the RAPID technique is scheduled for completion this year.

Evaluation Factor 2: Cost.

Non-recurring cost of using either RAPID or PGS is predominantly sunk at this time, hardware development being at a comparatively mature stage. IDA is doing cost evaluation.

Evaluation Factor 3: Intrusiveness.

In-principle intrusiveness concerns exist in that CGS measures dose rates from weapons at specific locations (Confidential/Restricted Data under current classification guidance). It is possible to conceal this information from the operator by building analytical capabilities directly into the instrument, and this has been done with both RAPID and PGS to some degree. In addition, it might be feasible to use the instrument in a "throw-away" mode -- use it once for the inspection, then turn the entire instrument over to the inspected party, who can disassemble it and verify that the instrument did not incorporate any means for surreptitious data telemetry, etc. In this case the issue of divulging design information becomes practically nonexistent.

Evaluation Factor 4: Operational impact.

The demonstration of PGS at a PK silo required less than 2 hours for data taking; analysis of the data suggests that as short a time as 45 minutes might suffice for this missile. A similar time would probably suffice for MMIII or any other weapons system in which the warheads are not shielded by a tractor motor. RAPID took somewhat longer (~4 hours), but the extra time stemmed from the fact that a neutron detector, requiring longer count times, was also part of RAPID. The gamma-ray part of RAPID is very similar to the PGS system, so if RAPID was used only for gamma rays, an hour would probably suffice. Use of a larger detector could, in principle, shorten this time somewhat, but in any event, most of the time would be spent moving the detector from one place to another rather than taking data, so the 45-minute figure is probably near the practical minimum time.

System down time is difficult to estimate owing to uncertainties in the mode of use. If it proved feasible to allow the instrument operator access to the launch tube/canister without observation from above -- admittedly unlikely, but a limiting case for purposes of analysis -- it is conceivable that no system down time would be imposed by the inspection, apart from that inescapably

associated with the visit to the silo/submarine and the period of data taking itself. The RAPID demonstration was conducted under these conditions. If the operators were permitted access to the launch tube, but were required to be under observation from above through an open silo door or hatch, an hour or so of down time might be expected. If the inspection had to be accomplished entirely from above -- for example, by using the SRS sensor arm -- several hours' down time might result, depending on the need to secure the silo door.

Evaluation Factor 5: Inspector's burden.

The entire PGS system weighs about 80 pounds, most of it in the form of shielding for the gamma-ray detector. The RAPID system is somewhat heavier because of the neutron detector. An in-principle weight limit of 30 pounds is probably reasonable, given careful attention to shielding design, for PK verification. For MMIII it might be possible to forego shielding altogether, in which case the weight could be reduced to 10 pounds or less. This is an open area for further R&D. It might also be necessary for the inspection team to carry spare batteries, etc., for power. The PGS system uses a rechargeable battery pack weighing several (<10) pounds that however could be supplanted by a D-cell pack with a little R&D. RAPID can operate with a microcomputer with on-board batteries good for an hour or so, or with a standard rate meter (Eberline ES-2) with batteries good for some hours.

Both RAPID and PGS were originally demonstrated using microcomputers. RAPID required basic computer literacy for use; PGS had a simplified operator interface consisting of four push buttons. The RAPID detector system was also demonstrated successfully with simple rate-meter electronics; however, use with a rate meter would pose intrusiveness concerns, as it would not be possible in this mode to disguise the count rate. Assembly and disassembly of either system involves connecting some cables between computer/rate-meter and detector. If the detector must be emplaced from above, for example via the SRS sensor arm, additional assembly is required.

No significant safety concerns exist with either RAPID or PGS. It is convenient to carry a check source for calibrations; a package of Coleman lantern mantles suffices for this purpose. If the detector must be emplaced from above, the usual safety precautions, associated with large objects above an open silo/hatch, would have to be followed. Similarly, if the system is emplaced from launch-tube level, appropriate safety procedures within the silo would have to be observed.

No special support requirements exist for RAPID or PGS, although access to some means for charging the batteries is convenient. If the SRS sensor arm (or something like it) must be used for emplacement, additional power may be required.

The current versions of PGS and RAPID are low-maintenance items requiring occasional inspection of the electronics. It might be

necessary to ruggedize the detectors before field use, particularly against thermal shock caused by extreme temperatures. The PGS system already contains some thermal shielding, but it is not clear that it suffices for Siberian conditions. The possibility exists that the detector might be kept at a constant temperature via the tape powered by the battery or other electrical supply; this would improve hands-off reliability (that is, likelihood that the system would function properly when turned on) at the cost of complexity and decreased battery life.

Evaluation Factor 6: Other.

Export control: not a problem with either RAPID or PGS.

Maturity: RAPID and PGS both demonstrated; fine-tuning for a specific application might be required. CGS as a technique is one of the oldest RVOSI techniques, going back at least to experiments performed in 1970.

Scenario dependence: Considerable. CGS has not been demonstrated, to the best of my knowledge, against any weapons system involving a tractor motor. Demonstrations of emplacement through the silo door are planned for this summer (enhanced RAPID).

COOLED OPTICALLY-STIMULATED LUMINESCENCE (COSL)

Note: COSL is essentially a form of circumferential gamma scanning (CGS) in which the movable gamma detector is replaced by an assemblage of dosimeters. Many of the conditions noted for CGS (ability to satisfy inspection objectives, concerns regarding spoofing by shielding or all-or-alloy weapons, intrusiveness) exist also for COSL: The CGS analysis should be consulted for reference purposes. Other dosimetric techniques exist that in principle could be adapted for RVOSI; however, only COSL has actually been proposed for this use, to the best of my knowledge.

INSPECTION OBJECTIVES

See CGS analysis.

EVALUATION FACTORS

Evaluation Factor 1: Reliability

It is not yet demonstrated that dosimetric techniques are as reliable as instrumental CGS, the reasons being that the combination of small "detector" size and absence of collimation (in COSL's current configuration) seriously impairs the signal/background ratio. Preliminary studies at the Los Alamos Simulation Facility suggest that COSL can identify the three SS-20 mocks in a close-packed configuration. No measurements have yet been done against weapons in the Peacekeeper configuration, but measurements are planned at F.E. Warren AFB in August. The innermost RV may prove difficult to recognize with the current COSL system. No data exist regarding the suitability of COSL for verification of two-tiered systems.

For discussions of spoofing, see the CGS analysis. An additional spoofing concern exists in that, unlike CGS, CNS, FATS or imaging systems, the COSL dosimeters could potentially be exposed to radiation before emplacement in the silo/tube (or after removal of the dosimeters from the silo/tube) sufficient to "fog" them and thereby corrupt the signature obtained, without detection by the on-site inspectors.

Evaluation Factor 2: Cost.

Being studied by IDA. The low cost of the sensor package (dosimeters) makes this technique potentially particularly suitable for throwaway use.

Evaluation Factor 3: Intrusiveness

See the CGS analysis. No spectroscopic capability exists with COSL even in theory; consequently concerns about the possibility of concealed information are ameliorated with this system. On the other hand, dosimetric information remains within the COSL dosimeters until it is actively erased. Consequently erasure must be a specified - and rigorously observed -- part of the inspection procedure.

Evaluation Factor 4: Operational impact.

(Note: The current COSL concept calls for a number of COSL dosimeters to be attached to a metal "hoop", which is dropped into place over the nose of the missile. It is left in place for some time sufficient to gain adequate statistics, then removed. The dosimeters are then read at some location removed from the silo/tube.)

System down time with this technique will probably be longer than for other CGS techniques. "detectors" are less efficient and take longer to gain statistically significant data. The ability to take data simultaneously at several points will partially, but probably not completely, compensate for this. Because of the envisioned mode of use, it will be more or less mandatory to open the silo door/hatch to install the dosimeters.

Evaluation Factor 5: Inspector's burden

The dosimeters themselves, combined with the hoop needed to emplace them, are very light; total weight, while scenario-dependent because different missiles require different-sized hoops, will be no more than a few tens of pounds, and possibly less. The electronics needed to read out the dosimeters currently weighs a few tens of pounds as well. Emplacement equipment might or might not be less substantial than the sensor arm possibly used with CGS or CNS; see below.

While no particular operator expertise is needed to emplace the dosimeters, operators would have to be trained in use of the electronics to analyze the data (i.e., read out the dosimeters). The current system requires considerable sophistication on the part of the operators. It is unclear how much simplification of the readout could be accomplished with R&D.

No safety concerns are perceived with this system except for those associated with the use of liquid nitrogen (see below).

In its current form, the readout system requires liquid nitrogen for cooling and 110V AC power. Further R&D would be likely to eliminate one or the other of these requirements, but not both: replacement of the liquid nitrogen with a Stirling-cycle refrigerator would cause the equipment to be more consumptive of power than would be compatible with battery operation (which could be feasible if the liquid nitrogen was retained).

Insufficient information exists on which to judge maintainability of this system.

Evaluation Factor 6: Other.

Export control: Probably not a problem.

Maturity: This technology is relatively immature for RVOSI. It has been demonstrated only at the Los Alamos Simulation Facility, and then in a relatively "easy" geometry.

Scenario dependence: See discussions under CGS.

GAMMA-RAY IMAGING

Note: This category groups the GRIS technology (LLNL), HgI₂ camera (EG&G), and Compton telescope (ISST/NRL).

INSPECTION OBJECTIVES

1. Determine that there are no more than X RVs.
No.
2. Determine the number of RVs.
No.
3. Detect the presence of nuclear warheads.
Yes, assuming they contain plutonium: all-oralloy weapons might or might not be detected.
4. Determine the number of nuclear warheads present.
Yes, assuming they contain plutonium.
5. Distinguish between nuclear warheads and RVs.
No.
6. Confirm the irreversibility of downloading.
No.

EVALUATION FACTORS

Evaluation Factor 1: Reliability.

Gamma-ray imaging clearly has the potential to function reliably in scenarios involving warhead counting, in principle; however, practical experience thus far has been somewhat mixed. The GRIS system functioned properly in tests at the Los Alamos Simulation Facility, but in the F.E. Warren demonstrations, only 9 of the 10 warheads were clearly discernible (evidence for the tenth warhead was ambiguous). The GRIS developers claim to have modified the instrument to solve some background problems encountered at Warren, and believe that these modifications will allow the instrument to locate the tenth warhead. Another round of work at Warren is planned for this August. The HgI₂ camera successfully counted warheads in tests at the Los Alamos Simulation Facility (SS-20 mockups and others) but has not been tested against an actual missile. The ISST System is still in the proof-of-concept stage, so no information exists on its actual reliability.

In addition to the usual gamma-ray spoof problems involving all-oralloy weapons and/or shielding, additional concerns exist with these techniques in situations where a tractor motor, or other massive object at the extreme front end of the missile, is present. A sufficiently large, massive object could shield radiation coming from warheads directly behind it and thereby prevent those warheads from being observed in the end-on geometry

employed by these techniques. It might, but not necessarily would, be possible to defeat concealment attempts based on this problem, by taking data both along the axis of the missile and at one or more off-axis positions; the viability of this approach would depend on the detailed geometry of the massive object and the RVs.

Evaluation Factor 2: Cost.

Being studied by IDA.

Evaluation Factor 3: Intrusiveness

It is difficult to evaluate the intrusiveness of imaging techniques, because so many factors come into the evaluation. GRIS, HgI2 and (presumably) the ISST system all have spectroscopic capabilities, the latter two of higher quality than GRIS, with concomitant concerns. As in the case of CGS, it would be necessary, and is probably feasible, to discard the spectroscopic information before presenting results to an inspector, and to convince the inspected party that no hidden storage of spectroscopic information was occurring. In contrast to CGS (including COSL), the technologies used for imaging are expensive, so throw-away use, as a means of reassuring the inspected party, is probably unfeasible. It is not clear whether dose rate concerns, such as exist for the various circumferential techniques, arise with these techniques: because the information presented to the inspector is a computed reconstruction, rather than raw data, it might not be possible to infer dose rates from anything the inspector actually sees. A particularly complex question is whether the images themselves contain sensitive information. Both GRIS and the HgI2 system present images in the form of arrays of "pixels", each pixel representing signals from a region of space typically some inches square. (It is reasonable to assume that the ISST system will also use this approach to image presentation.) If the pixel size is chosen so that the pixel is larger than the emitting source, it is impossible to gain quantitative information about the size of the individual radiation sources in the object being imaged. On the other hand, the mere fact that a given pixel size is greater than the size of the sources -- i.e., pit or radiation case - may give an adversary valuable information about the warhead being imaged. This question merits careful study. Related questions exist regarding the use of the imaging system off-axis to avoid the central-obstruction problem mentioned under factor 1: might sensitive information regarding the length of the physics package be revealed as a result? Again, research is required to address such questions.

Evaluation Factor 4: Operational impact.

With all of these approaches it is assumed that the missile will be viewed from above. Consequently it is necessary to open the silo/hatch, secure the opening, etc. with all the operational impact that this entails. Additionally, when GRIS was used at Warren, the detector system was suspended from the trailer

emplaced (by the Air Force) over the open silo, and that emplacement took a little time (1 hour). It is reasonable to expect that the HgI₂ and ISST systems would operate in a similar mode and that one to a few hours' setup time, after the silo door/hatch was open, would be required.

The time required for data acquisition is expected to depend both upon the scenario and the details of the instrument being used. Data acquisition for GRIS at Warren was complete within less than 4 hours, and a similar data-acquisition time at the Los Alamos Simulation Facility produced abundant data. The HgI₂ work at the Simulation Facility required somewhat more time to generate images, because the camera itself is smaller, hence less efficient, than that used in GRIS. Lacking a particular piece of ISST hardware, it is impossible to judge how long data acquisition would take, but it is reasonable to assume that a few hours more than 1, less than 10 -- would suffice.

Evaluation Factor 5: Inspector's burden.

Insufficient information exists on the ISST system to evaluate its eventual size and weight. GRIS as used at Warren had a total system weight of roughly 150 pounds, much of it in the form of lead shielding in the detector array. The HgI₂ system used at Los Alamos was itself considerably lighter, but the fragility of the HgI₂ crystal (one of few spectroscopy-grade systems in existence) required it to be shipped in heavy, bulky shipping containers; the effective system weight would probably be nearly as high as that of GRIS. This might decrease as the technology becomes more mature.

GRIS and the HgI₂ camera currently present images via microcomputer and require both computer expertise and knowledge of the electronics to operate. It is unclear to what extent the operator interface electronics, etc., could be streamlined to make use possible by an intelligent, but not necessarily scientifically-oriented, inspector. These systems are relatively complex and would probably require some pre-deployment checkout, which would have to be performed by a relatively knowledgeable operator.

Safety concerns existed with GRIS at Warren, revolving around the fact that a relatively heavy detector package was being suspended directly above the missile. Standard Nuclear Surety procedures sufficed to address these concerns. No other safety concerns are obvious, although it would be desirable to include a small gamma-ray check source with the equipment when an inspection occurred.

GRIS and the HgI₂ camera both require 110 V AC power in their current forms, and it would be reasonable to expect an eventual Compton camera (ISST) to have similar requirements. The ISST system may also require liquid nitrogen, depending on the state of high-resolution detector technology when (and if) this system reaches maturity.

The relatively complex electronics required for these techniques may pose maintenance problems. It probably is not practical to trouble-shoot the electronics on a module-by-module basis, so that entire spare electronics packages would have to be carried. It is unclear whether two electronics packages could be constructed that are so nearly identical as to require no in-the-field "tuning" (setting timing, etc.); if not, at least one of the operators would have to have considerable electronics expertise in case problems did occur.

Evaluation Factor 6: Other.

Export control: Reconstruction of images from raw data is somewhat computation-intensive and requires a reasonably powerful microcomputer. However, it clearly is not required that a computer be used that is so high-powered as to be non-exportable. No other export problems are obvious.

Technology maturity: Moderate for GRIS, low for HgI^2 and the Compton telescope. Fabrication of high-quality HgI^2 crystals is difficult, and only a few crystals suitable for use in an imaging camera now exist. The remainder of the technology (e.g. coded aperture for forming the image) is reasonably mature.

Scenario dependence: See analysis under Evaluation Factor 1.

"ELEPHANT GUN"

Unlike other techniques we are considering, the "elephant gun" (a highly collimated gamma-ray detector) looks not for RVs but for the absence of RVs, by seeking radiation in some volume of space previously agreed not to contain a radiation emitter (i.e. a weapon). Its usefulness is limited to determining downloading. The operational concept is sufficiently different from other techniques being considered that several of the objectives/criteria do not apply.

The operational concept of the elephant gun is as follows: The treaty partners agree, on the basis of prior investigation (probably including solid modeling), that a previously-MIRVed system, being de-MIRVed under terms of the treaty/agreement, should not contain a warhead within some particular volume of space, a volume extending all the way through the missile along some line of sight., whereas the fully-MIRVed system does harbor a warhead in this volume. (This agreement obviously is a matter of negotiation and protocol, and determination of the satisfactory line(s) of sight is not left to the inspector!) For field verifications, the detector, after calibration and checkout, is placed so that its collimator extends along the line(s) of sight, and a spectrum is acquired. Evidence of radiation from a warhead in this spectrum constitutes evidence that the required de-MIRVing did not occur.

EVALUATION FACTORS

Factor 1: High confidence.

Confidence is difficult to judge. In principle, gamma-ray spectroscopy is an excellent way to locate a warhead, even an all-or-alloy one, and therefore is also a good way to confirm the absence of a warhead. Practical difficulties arise in that the detector must be very highly collimated indeed to avoid seeing radiation from neighboring warheads in allowed/admitted positions. These problems are remediable with a long count time.

Spoofability concerns exist as for other gamma-ray techniques: all-or-alloy warheads might not be seen, and shielding might remove the signal from some warheads that are present. The fact that a long counting time could be employed and that x rays from shielding material might be seen could counter this potential spoof to some extent. R&D is needed to examine spoofing possibilities.

Factor 2: Cost.

Usual considerations apply. A hidden cost unique to this concept is the need to perform extensive solid modeling, not in the course of developing the technology (which is basically off-the-shelf) but in the course of negotiating its acceptance. Solid modeling would be an immense aid in determining the direction in which to "aim" the detector: the detector should be "aimed" so that its line of sight includes a warhead in the fully-MIRVed weapons system but not in the de-MIRVed one. Multiple lines of sight might be required for satisfactory verification. A superior solid-modeling capability would be essential to demonstrating that such lines of sight do exist for any particular weapons system (or that no such lines of sight exist for some) and should be considered part of the development cost. One or two man-years' effort is probably reasonable for this purpose.

Factor 3: Intrusiveness.

Since this technique relies upon data taking where no RV is believed to be present, intrusiveness concerns are practically nonexistent if all goes well: the treaty partners agree on the line of sight, and thereafter, if any gamma rays are found from a warhead in that line of sight (a situation that would normally involve the compromise of classified information), the warhead's owner has little to complain about since the warhead is not supposed to be there in the first place. The main concerns that arise have to do with misuse of the equipment via misalignment that causes a warhead to come into the field of view, either accidentally or as a result of tampering with the alignment system by the inspector. Procedures for using the equipment would have to take this possibility into account.

Factor 4: Operator's burden.

The required electronics is quite light (~10 pounds apart from the collimator) and requires no unusual precautions regarding safety, cryogenics, etc. The collimator might weigh as much as a few tens of pounds. If the inspector is burdened with the hardware for emplacing and aligning the detector, an indeterminate extra weight burden would exist. However, it might be feasible to expect the weapons system's owner to provide such fixtures, as they will be unique to each weapons system and it is in the system's owner's

interest, rather than the inspector's, to prevent the ill effects of misalignment.

Training for a system like this should be particularly easy from the inspector's viewpoint, taking no more effort than the current INF detector and possibly less. It might be necessary, however, also to train the weapons system's owner(s) in correct alignment./mounting procedures.

Factor 5: Operational impact.

This is extremely scenario-dependent and hinges on the question of what lines of sight are used. Data taking at each line of sight should probably take 15 minutes or less, but a certain amount of time will be required for setting up the line of sight and assuring alignment. With many missile systems it should be possible to do the measurements end-on, obviating some of the usual access requirements; only detailed solid modeling, however, would determine what access is required for any particular weapon.

Baselining is one of the more sensitive components of this technique, as it would be necessary to take data on a missile that has not been de-MIRVed at some point, in order to demonstrate to the satisfaction of the treaty partners that a re-MIRVed missile would be successfully detected. This baseline might well contain Restricted Data and would have to be protected in some way. Practically speaking, a baseline would probably be required for each weapons system prior to de-MIRVing and possibly for each de-MIRVed configuration to verify the predictions of solid modeling. However, the data base generated by the baselining need only consist of a few detector positions and alignment directions so that sensitive information obtained in the spectra themselves need not be preserved or even seen by the inspectors.

Factor 6: Other.

Maturity: This technique is notable in that, while the hardware is extremely mature (all the important components but the collimator can be bought off-the-shelf, and the collimator is not a difficult fabrication problem), the operational concept is immature and would require an extensive and careful R&D effort versus realistic (though not necessarily "real") configurations.

Exportability: Not a concern.

Scenario dependence: Extreme. An alignment procedure and possibly collimator would have to be developed for each weapons system, and for some the technique might not be feasible at all.

FISSION ASSAY TOMOGRAPHY SYSTEM (FATS)

INSPECTION OBJECTIVES

1. Determine that there are no more than X RVs.
Unclear (see objective 5) but probably not.
2. Determine the number of RVs.
Again, see objective 5.
3. Detect the presence of nuclear warheads.
Yes.
4. Determine the number of nuclear warheads present.
Yes.
5. Distinguish between nuclear warheads and RVs.
In contrast to other passive radiation techniques, FATS might be able to do this, although the capability has not yet been demonstrated. FATS relies upon simultaneous observation of radiation in two or more detectors; differences in time of arrival of the radiation at the various detectors are compiled, and used in an eventual tomographic reconstruction. Presence of a non-radiation-emitting but massive object - in this context, an RV -- might be detectable because such an object would "cast shadows" on the detectors nearest it. The technology developers indicate that they have not attempted experiments with massive, inert objects and believe the problem of detecting them to be difficult, but not necessarily impossible. R&D is needed.
6. Confirm the irreversibility of downloading.
No.

EVALUATION FACTORS

Evaluation Factor 1: Reliability

The most recent tests of FATS at the Los Alamos Simulation Facility indicate that the technique works reasonably reliably, although an earlier version of FATS was less reliable. The current version located the SS-20 mockups, plus an additional special source, correctly, albeit in a less close-packed geometry than was tested with some other techniques. FATS will be demonstrated at F.E. Warren AFB in August, at which time its reliability versus a PK will be examined.

FATS may be less spoofable than some other passive techniques. Use of shielding to mask an undeclared weapon might be detectable owing to the "shadows" cast on some detectors by radiation from declared weapons, at least in those cases where no non-radiation-emitting, massive object is expected to be present; R&D is needed to evaluate this possibility. Spoofs based on all-or-alloy weapons may be possible.

Evaluation Factor 2: Cost.
Being studied by IDA.

Evaluation Factor 3: Intrusiveness.
Many of the same intrusiveness issues exist for FATS that are discussed under "Gamma-Ray Imaging", particularly for GRIS. Additionally, the need to place a cumbersome array of detectors in the vicinity of the weapons practically guarantees that nuclear surety issues will arise.

Evaluation Factor 4: Operational impact.
Because FATS is still in prototype form, it is difficult to assess the operational impact of a fully fieldable FATS apparatus. The demonstration at Warren will involve dropping the detectors to the maintenance level via the personnel access hatch (PAH), with personnel then assembling the hoops on which the detectors are mounted and emplacing them. If this mode of operation proves acceptable in the field (unlikely for reasons discussed under CGS), system down time for delivering the system may be quite short. If the detectors must be dropped into place through the open silo door/hatch, the usual down time associated with opening/closing the door/hatch will be required. In either case, it will be necessary to spend some time doing tedious setup of detectors (positioning properly, cabling to the electronics package) either on the maintenance level or topside; it is not clear at this time how much time this will take (perhaps an hour), but the Warren work will shed some light on the subject.

Time required for data acquisition will probably be quite scenario dependent, because count rate for FATS goes not as the inverse square of the distance between radiation source and detector, but rather as the inverse fourth power of distance. A counting time of a few (<6) hours sufficed at the Simulation Facility to identify warheads; whether this time will suffice at Warren is open to question, the PK being relatively large (although the spacing between detectors at Warren will be no different than at the Simulation Facility).

Evaluation Factor 5: Inspector's Burden.
FATS in its current form is extremely heavy (~1000 pounds) and cumbersome, most of the weight and bulk residing in two large crates of electronics that do not go down into the silo/launch tube but must be placed topside. Work is in progress to reduce the size of the electronics packages, but just the detectors themselves weigh over 200 pounds in aggregate; consequently, even a dramatic (and improbable) tenfold reduction in the size of the electronics will still leave a system weighing several hundred pounds.

FATS is expected to be roughly as easy to use as one of the gamma-ray imaging systems (q.v.): in its current form, computer and electronics-literate operators are required, but R&D may produce a simplified operator interface. Some tedious setup will be

required, as it is necessary to station up to 20 detectors at various locations around the missile, and each of these detectors must be cabled to the electronics package.

No safety concerns are obvious with this system, apart from the usual ones associated with working around an open silo door/hatch if appropriate.

The complex electronics in the current version of FATS require 110 V AC. It is unclear, but in my opinion doubtful, whether a FATS system can be built that is battery powered.

Maintenance is currently quite a headache owing to the large number of cables, electronics modules, etc., used in the system. If a particular electronics module goes bad, the operator is faced with the unpleasant choice between replacing the single module (requiring extensive retiming of the electronics) and swapping out an entire electronics package (requiring possibly several hundred pounds of extra electronics). Troubleshooting of the electronics requires greater expertise than with some other systems.

Evaluation Factor 6: Other.

Export control: similar to gamma-ray imaging; no intrinsic problems, but it may be necessary to use a less powerful computer for image reconstruction than would be desirable.

Maturity: low to intermediate. A system has been tested at the Simulation Facility, and will shortly be demonstrated at Warren; however, the developers indicate that upgrades will be required before the system can be considered fieldable by anyone but themselves.

PRELIMINARY EVALUATION OF X-RAY FLUORESCENCE

Contractor: SRS Technologies

Evaluator: Gary Phillips

(Rev. 1, 7/22/92)

INSPECTION OBJECTIVES

1. Determine that there are no more than X reentry vehicles.
No, looks only for nuclear warheads.
2. Determine the number of reentry vehicles
No.
3. Detect the presence of nuclear warheads
Yes.
4. Determine the number of nuclear warheads present
Yes.
5. Distinguish between nuclear warheads and reentry vehicles
No.
6. Confirm the irreversibility of downloading/Confirm bus changes
No.

EVALUATION FACTORS

1. High confidence in the ability to do the inspection

1.1 Reliability

The x-ray fluorescence method relies on exciting the outer cover of the warhead, made of uranium or other high atomic number material, causing it to emit K x-rays. Requires knowledge of the cover material and position of the RV's. Given this, the method has a high reliability. The method would not detect an RV with a cover made of a different material unless multiple windows were set which could reduce the reliability. It would likely not detect an RV which was not in the expected position.

1.2 Spoof Resistance

The method could be spoofed by using a different cover material, although this is perhaps unlikely as it would require a design change for the warhead. It is also possible to shield the relatively low energy K x-rays. The mean free path in lead is less than 0.2 mm for the strongest uranium K x-ray at 98 keV. One or more RV's could thus be shielded by a lead cover for a

relatively small weight penalty. This could be detected by looking for lead x-rays, again at the cost of complexity. However, a graded shield could reduce the lead x-rays below detectability.

2. Cost

IDA is doing cost evaluation. SRS built and tested the prototype for a cost of \$750,000.

3. Intrusiveness

3.1 Information gained beyond that required for inspection

The method either requires prior knowledge of the material of the outer cover or requires setting windows on the possible materials. The latter could reveal additional information about that material. In addition, the Ge detector used for the x-rays could detect gamma rays from the nuclear materials inside the warhead which could reveal design information.

3.2 Can potentially intrusive info be masked and inspection still be completed

Software and/or hardware can be designed not to reveal the potentially intrusive information. The difficulty would be to insure to the satisfaction of the inspected party that no additional information can be obtained.

4. Operational Impact

4.1 System downtime

Peacekeeper demo required raising the missile in the silo, a time consuming operation. The inspection plan outlined a 6 hour timeline from arrival on-site to closure of the silo door. Details of the actual operation are contained in a classified appendix. A second demo was planned to count from an angle above the warheads without raising the missile. This took about two hours to set up above the silo. However, the test was canceled due to high winds.

4.2 Operational Requirements

Inspection time after the missile was raised was projected at 2 hours. Actual counting time in the first test was rapid, less than one minute per position.

The method requires raising the silo hatch but does not require removing the shroud.

5. Inspector's Burden

5.1 Weight and volume

Sensor arm and support total weight - 1200 lb.

Sensor arm assembly weight - 235 lb. Dimensions approx. 1' x 12'.

5.2 Ease of use

Simple ratemeter operation.

5.3 Safety

X-ray emission in the beam is 22 rad/hr. This is a very hazardous level to personnel and procedures would have to be taken to exclude the possibility of exposure to the direct beam. Behind and to the side, x-ray levels are <4.7 mrad/hr at 2 m and about 2 mrad/hr at 3 m. The occupational limit is 1250 mrem/quarter, and the limit to the general public is 125 mrem/quarter (1 rad X-ray = 1 rem.) These may be lowered in the future. Any area with a dose rate greater than 5 mrem/hr or 100 mrem in any 5 consecutive days must be posted as a radiation area. If an inspection takes 2 hours and an inspector receives 9 mrem, then he could conduct 138 inspections per quarter without exceeding the occupational limit. However, the typical radiation worker receives much less than the limit.

5.4 Special requirements

110/120V - 10A power. Can operate on 220V generator.

The Ge detector must operate at liquid nitrogen temperatures. A mechanical cooler would probably be required as liquid nitrogen is not always available or convenient to carry in.

Current design is silo dependent. The arm just clears the nose of the missile as it is lowered into the silo. As it rotates around the silo the arm is kept in position by supporting part of the weight with a wheel which rolls around the silo wall. Other silos will have different dimensions and may not offer a smooth regular surface for the wheel.

5.5 Maintainability

The Ge detector is relatively prone to failure and spares would be required. However this is a relatively small lightweight item and the system can be built so that the detector can be easily swapped out. The x-ray generator can probably be ruggedized as can the mechanical equipment.

6. Other Factors

6.1 Export control policy at this time

Should not be a problem.

6.2 Technology maturity

Has been built and demonstrated in one test.

6.3 Scenario dependence

The system was designed for a silo. In the Phase II demonstration, the hatch had to be opened and the missile raised in the silo. In the aborted Phase II/B operation, the silo door hatch had to be open but the missile would not have had to be raised.

SRS has outlined an inspection procedure for a rail mobile system. It would have to be done in a maintenance area where the front end of the missile was removed from the rail car and canister.

For sub launched missiles it would require that the missile be raised from the tube.

6.4 References:

1. Richard Nori and Michael Short, "Warhead Verification Under START, Phase II-Final Report." BMO-TR-92-04, 30 November 1991, SRS Technologies, 1500 Wilson Blvd., Arlington, VA 22209. Telephone (703) 522-2891.

2. Richard Nori and Michael Short, "Warhead Verification Under START, Phase II/B-Final Report." BMO-TR-92-04, 30 November 1991, SRS Technologies, 1500 Wilson Blvd., Arlington, VA 22209. Telephone (703) 522-2891.

(These reports also describe a passive neutron system which is not included in this evaluation.)

PRELIMINARY EVALUATION OF GAMMA-RAY HODOSCOPE

Performer: Argonne National Laboratory

Evaluator: Gary Phillips

(revised, 31 August 1992)

INSPECTION OBJECTIVES

1. Determine that there are no more than X reentry vehicles.
Yes. (Would require software to conceal from the inspector the actual number of RVs found.)
2. Determine the number of reentry vehicles
Yes.
3. Detect the presence of nuclear warheads
No. (However, it could detect the presence of high-density material.)
4. Determine the number of nuclear warheads present
No. (see comment above)
5. Distinguish between nuclear warheads and reentry vehicles
Possibly, due to differences in material density.
6. Confirm the irreversibility of downloading/Confirm bus changes
No.

EVALUATION FACTORS

1. High confidence in the ability to do the inspection

1.1 Reliability

The Hodoscope method is a gamma-ray transmission imaging technique using tomographic reconstruction. It uses a ^{60}Co source with 32 small NaI detectors and has been demonstrated on ten lead mockups in a Peacekeeper configuration. It detects the dense, high atomic number (Z) material of the warhead. It would probably not detect an RV that did not have high Z material although there may be a ghost image. The imaging technique typically uses a 12 angle reconstruction. The resulting image is low resolution; individual objects are clearly identified but no detailed image is obtained. There is no requirement for baseline information.

1.2 Spoof Resistance

Unlike passive methods, transmission techniques are difficult to spoof since shielding is detectable as additional absorber.

2. Cost

IDA is doing cost evaluation.

3. Intrusiveness

3.1 Information gained beyond that required for inspection

The gamma-ray detectors have the potential of obtaining passive mode data on nuclear materials and design. However, this would require a much longer exposure than needed for hodoscope imaging. The hodoscope image itself does not have sufficient detail to reveal design information. The resolution is limited by the size of the detectors.

3.2 Can potentially intrusive info be masked and inspection still be completed

Yes, in operation the ^{60}Co gamma rays would swamp any gamma rays from the warheads.

4. Operational Impact

4.1 System downtime

In the peacekeeper scenario, it would require raising the missile in the silo, since a direct line-of-sight through the warheads is needed. The actual inspection would require only about one minute per viewing angle. Inspection time would likely be limited by the time needed to change angles.

4.2 Operational Requirements

Inspection time after the missile was raised would be mostly the time to get the instruments in position and to raise them again after the inspection. This would take perhaps 2 hours total. Actual counting time would take 20-30 minutes.

The method requires access to the silo but does not require removing the shroud.

5. Inspector's Burden

5.1 Weight and volume

System tested only in lab version. A field system for another application uses 6-8 cases, all easily one-man portable. Electronics now comes in two aluminum cases. Reconstruction software will be done in a laptop PC.

5.2 Ease of use

Manual calibration typically takes 4-6 hours. This could probably be automated. Once calibrated the system was stable and did not have to be recalibrated for each use. In the field the system would need calibration unless the detectors were temperature stabilized.

Data collection and reconstruction uses a PC, could be automated.

5.3 Safety

System uses a 10 mCi ^{60}Co source. Dose rate is 10 mrad/hr at the center of the target which is relatively small compared to the dose rate from the SRS x-ray source. The ^{60}Co source is shielded except in the direction of the object to be inspected.

5.4 Special requirements

Standard 110V or 220V, electrical power (should run on one 15 A circuit.)

NaI detectors would have to be protected from thermal shock. Temperature would need to be stabilized during use to prevent gain drifts.

5.5 Maintainability

Electronics would need to be ruggedized. The detectors require no special maintenance.

6. Other Factors

6.1 Export control policy at this time

Should not be a problem.

6.2 Technology maturity

System has been demonstrated on a Peacekeeper-like mockup in the lab. A system has been fielded for a different application.

6.3 Scenario dependence

The system would be most useful in a silo. For a rail mobile system it may be possible to image through the canister. For sub launched missiles it would require that the missile be raised from the tube.

6.4 References

C.E. Dickerman et al., "Demonstration of Gamma-Ray Transmission Hodoscope Technology for Warhead Counting," ANL/ACTV-90/4, 31 August 1990, Argonne National Laboratory, Argonne, IL 60439. Telephone (708) 252-4622.

PRELIMINARY EVALUATION ASSOCIATED PARTICLE IMAGING

Performer: Special Technologies Laboratory

Evaluator: Gary Phillips

INSPECTION OBJECTIVES

1. Determine that there are no more than X reentry vehicles.
Yes.
2. Determine the number of reentry vehicles
Yes.
3. Detect the presence of nuclear warheads
Probably.
4. Determine the number of nuclear warheads present
Probably.
5. Distinguish between nuclear warheads and reentry vehicles
Yes.
6. Confirm the irreversibility of downloading/Confirm bus changes
No.

EVALUATION FACTORS

1. High confidence in the ability to do the inspection

1.1 Reliability

System uses a sealed tube neutron generator (STNG) as a source and detects neutron capture gamma rays. X-Y imaging is accomplished by detecting position of associated alpha particle produced with the neutron by $^3\text{H}(\text{d},\text{n})^4\text{He}$ reaction. Z imaging is by neutron time-of-flight. Expected resolution is 2 cm (X,Y) and 4 cm (Z). Lab demonstrations show rather coarse resolution. Requires nanosecond coincident timing circuits. Uses NaI detectors for fast timing, which limits energy resolution. Method is several years away from a fieldable system.

1.2 Spoof Resistance

Not enough data to date to estimate spoof resistance.

2. Cost

Not mature enough to evaluate.

3. Intrusiveness

3.1 Information gained beyond that required for inspection

Potentially could identify types and amounts of nuclear material by taking time-of-flight gated spectra.

3.2 Can potentially intrusive info be masked and inspection still be completed

Would require software or hardware techniques to prevent revealing intrusive info.

4. Operational Impact

4.1 System downtime

Not enough data to evaluate. Inspection could be done from above without raising the missile in the silo.

4.2 Operational Requirements

Field of view is about $\pm 17^\circ$. Would require about 3 views for peacekeeper, 20-30 minutes per view.

5. Inspector's Burden

5.1 Weight and volume

STNG is about 4" diam. x 16" and fits inside a high voltage power supply that is 19"d x 14". Most of weight and volume would be in detectors and electronics. Large NaI detectors are needed to stop the high-energy capture gamma-rays.

5.2 Ease of use

System currently would require some training to set up and use.

5.3 Safety

Neutron source is relatively small 10^6 to 10^7 neutrons/s, which would not pose a safety hazard.

5.4 Special requirements

Standard 110V or 220V, electrical power.

NaI detectors would have to be protected from thermal shock. Temperature would need to be stabilized during use to prevent gain drifts.

5.5 Maintainability

Electronics would need to be ruggedized. The detectors require no special maintenance. The tubes have lasted for several thousand hours of use in the lab. If the tube sits on the shelf for 6 months it suffer from ^3He build-up and could take days or weeks of use to fully recover.

6. Other Factors

6.1 Export control policy at this time
Should not be a problem.

6.2 Technology maturity
Method is several years away from a fieldable system.

6.3 Scenario dependence
Could probably be used through the canister on a rail mobile system. On a sub launched system, would require raising the missile from the tube.

6.4 References

1. EGG-10617-3008, "Current Status of the Associated Particle Imaging System at STL," January 10, 1992, Special Technologies Laboratory, Santa Barbara, CA 93111. P.O.C. Paul Hurley or Al Beyerle, telephone (805) 964-7073.

2. LA-11876-MS, "An Application of the Associated-Particle Technique to Treaty Verification," July 1990, and LA-11423-MS, "Three-Dimensional Imaging Using Tagged 14.7 MeV Neutrons," October 1988, Los Alamos National Laboratory, Los Alamos, NM 87545. P.O.C. Ed. Ussery, telephone (505) 667-1751.

3. P.O.C. Ed Rhodes, Argonne National Laboratory, Argonne, IL 60439. Telephone (708) 252-4575.

RVOSI USING ACOUSTICS
ARS, FRM, LFM/SVR

Evaluator: Dr. Earl N. Powers
SYSTEM PLANNING CORPORATION

INSPECTION OBJECTIVES

1. Determine that there are no more than treaty specified number of RVs.

Yes, if signature templates are available for known RV counts.
(This System does not image as such; it only provides a signature)

2. Determine the number of RV's

Yes, if the measured signature can be matched to that of a known number of RVs;
known signature data base required.

3. Detect the presence of nuclear warheads.

Maybe, only if the presence of nuclear warheads causes a significant difference in the
reference signature templates.

4. Determine the number of nuclear warheads

Possibly, the acoustic system performs template matching against a baseline data
base

5. Distinguish between nuclear and non-nuclear warheads.

Maybe, the previous comments apply, the acoustic systems are only sensitive to the
vibrational modes arising because of physical configurations, material types, and
density distributions.

6. Confirm the irreversibility of downloading/bus changes.

Possibly, the previous comments apply.

RVOSI TECHNOLOGY STUDY

Evaluation of ARS

Evaluation Factor 1. Confidence Level

ARS experiments have demonstrated potential utility for CW-OSI applications. Munitions signatures have been obtained that are sensitive to fill level and the composition of the fill. At this time ARS is unproven for RVOSI situations. The interior RV structure may not be tightly acoustically coupled to the outer shroud; in such a case ARS may have difficulty supplying an adequate interior signature. ARS experiments typically measure the signature at a single point. Single point measurements are potentially susceptible to spoofing since the spoofer need only generate false acoustic in the vicinity of the single measuring point.

Evaluation Factor 3. Intrusiveness

The ARS RV signature is potentially nonintrusive since it provides a spectral measurement of the acoustic properties of the test object, not an acoustic image of the interior. Standoff measurements are possible by using a laser receiver. There need be no physical contact with the TLI unless there is a need to place a reflector on the TLI surface for standoff laser measurements. Alternately, ARS may employ contact transducers in which case it would be necessary to physically touch the TLI.

Evaluation Factor 4. Operational Impact

System downtime is expected to be short - 10 m to 1 h (however, this estimate does not include the time which may required for the laser system to stabilize, 20 - 30 minutes)

There must be no interfering acoustic cover such as a tarp that could interfere with either contact or standoff laser measurements

Evaluation Factor 5. Inspector's burden

The ARS system can be easily man portable since it consists essentially of a sweep frequency generator, the receive transducer (laser or contact) and an instrument (such a recording spectrum analyzer) to store and display the measured spectrum signature. Set up and operation of the equipment should not be difficult. The receive transducer must be attached to the TLI or the laser aimed at the appropriate spot, and the output signal cabled to the recording instrument, the equipment turned on and perhaps calibrated, then the TLI would be insonified either by a contact transducer or remote

speaker to generate the signature. Set up, use and break down time is estimated at 10 m to 1 hr. The system might be battery powered and could be made very rugged and reliable. Downside factors include safety considerations arising from the physical contact with the TLI and the resultant intrusiveness. The laser impingement might also be viewed as a safety consideration. Also, the laser system may not be as rugged as most acoustic instruments. It is estimated that set up, use and break down time would be about 20 m to 1 hr, perhaps somewhat longer if the laser requires precise, alignment and/or warmup time.

Export control constraints

There are probably no export control constraints since similar equipment has been used world-wide for non-destructive evaluation.

Technological maturity

ARS is about as mature as FRM. It is judged to be at the laboratory level, although it has been used in the field to make signature measurements on munitions with encouraging results. There have been no reported experiments using RV type enclosures. The previous experiments used off-the-shelf equipments that would require at least repackaging for field use.

Scenario dependence

There must be no covering such as a tarp, hatch cover, etc that would interfere with measurements.

ACOUSTICS FOR RVOSI

Acoustic Resonance Spectroscopy (ARS)

ARS employs two acoustic transducers, one for insonification and the other for reception. All the early experiments used contact transducers. More recent work demonstrates that standoff operation is possible. In the latter case a loudspeaker is used for insonification, and the response is measured by reflecting a laser beam off the test object.

ARS uses a sweep frequency signal as the insonification source. Typically the signal will sweep from 5 kHz to perhaps 30 kHz. Other frequency ranges might be used depending upon the test object. The sweep rate is low; a full range sweep might take 10 to 20 seconds. Since the acoustic energy is spread out in time, the peak insonification level is low. Power levels on the order of 1 mW are adequate, at least, in some applications using contact transducers.

The measured output resulting from the insonification is the frequency response spectrum of the test object. The spectrum will exhibit peaks which correspond resonances arising because of the physical structure of the test object and the properties of the construction materials. The resonance pattern constitutes a signature for the test object.

The application of ARS to RVOSI has not been fully explored yet, but ARS has shown encouraging results in experiments aimed at determining the contents of munitions. ARS can be used to identify the munitions fill level and can distinguish between different fill compositions.

RVOSI TECHNOLOGY STUDY

Evaluation of FRM

Evaluation Factor 1. Confidence Level

FRM experiments have demonstrated potential utility for CW-OSI applications. Munitions signatures have been obtained that are sensitive to fill level and the composition of the fill. At this time FRM is unproven for RVOSI situations. The interior RV structure may not be tightly acoustically coupled to the outer shroud; in such a case FRM may have difficulty supplying an adequate interior signature. FRM experiments typically measure the signature at a single point. Single point measurements are potentially susceptible to spoofing since the spoofer need only generate false acoustic in the vicinity of the single measuring point.

Evaluation Factor 3. Intrusiveness

The FRM RV signature is potentially nonintrusive since it provides a spectral measurement of the acoustic properties of the test object, not an acoustic image of the interior. However the equipment required may be viewed as intrusive since it requires physical contact with the outer shell of the TLI.

Evaluation Factor 4. Operational Impact

The FRM system is functionally simple, and measurements can be made quickly. System downtime will be short - 10 m to 1 h.

There must be no interfering acoustic cover such as a tarp since it would interfere with contact insonification.

Evaluation Factor 5. Inspector's burden

The FRM system can be easily man portable since it consists essentially of an instrumented hammer (or other actuator), the receive transducer and an instrument (such a recording spectrum analyzer) to store and display the measured spectrum signature. Set up and operation of the equipment should not be difficult. The receive transducer must be attached to the TLI and the recording instrument, the equipment turned on and perhaps calibrated, then the TLI is rapped with the hammer one or more times to obtain the signature. Set up, use and break down time is estimated at 10 m to 1 hr. The system might be battery powered and could be made very rugged and reliable. Downside factors include safety considerations arising

from the physical contact with the TLI and the resultant intrusiveness. Also, FRM insonification has a high peak level compared to ARS.

Export control constraints

There are probably no export control constraints since similar equipment has been used world-wide for non-destructive evaluation.

Technological maturity

FRM is judged to be at the laboratory level, although it has been used in the field to make signature measurements on munitions with encouraging results. There have been no reported experiments using RV type enclosures. The previous experiments used off-the-shelf equipments that would require at least repackaging for field use.

Scenario dependence

The major scenario dependence arises because of the need for contact measurements. The TLI must not be covered with any type of structure that would prevent coupling of the acoustic energy into its interior.

ACOUSTICS FOR RVOSI

Frequency Response Measurement (FRM)

FRM measures the vibrational frequency response of a test object as a result of insonification by an acoustic impulse. Most FRM experiments have used an instrumented hammer containing a transducer which directly measures the impulse generated by the hammer tap. The vibration generated by the impulse is recovered by a contact transducer located elsewhere on the test object.

The ratio of the measured vibration output spectrum to the spectrum of the hammer impulse is the transfer function of the test object. The transfer function spectrum will exhibit peaks and valleys as a result of resonances. The resonant frequencies are determined by the physical structure of the test object and the properties of the construction materials. The spectral pattern constitutes a signature for the test object.

The application of FRM to RVOSI has not been fully explored yet, but FRM has shown encouraging results in experiments aimed at determining the contents of munitions. FRM can be used to identify the munitions fill level and can distinguish between different fill compositions.

RVOSI TECHNOLOGY STUDY

Evaluation of LFM/SVR

Evaluation Factor 1. Confidence Level

The LFM/SVR concept development was guided by the requirements of the OSI scenarios; consequently it is theoretically well suited for RVOSI. One of the design considerations was the incorporation of a high degree of spoof resistance. LFM/SVR suffers from existing only on paper; there has not yet been any proof of principle.

Evaluation Factor 3. Intrusiveness

The LFM/SVR system is designed for standoff measurements. Acoustic transmission through the skin of the TLI will inhibit detailed interior viewing; the measured signature is potentially nonintrusive.

Evaluation Factor 4. Operational Impact

The system downtime is estimated to be short - 10 m to 1 h.

Evaluation Factor 5. Inspector's burden

The LFM/SVR system is expected to be highly portable since most of the system is implemented in software which will run on a notebook computer. It is expected to be a rugged and reliable system. Set up, use and break down time are estimated at - 20 m to 1 hr.

Export control constraints

Probably none, similar components used world-wide.

Technological maturity

LFM/SVR is strictly at a conceptual stage. The theory is complete, but no experimentation has yet begun.

Scenario dependence

The LFM/SVR system architecture was developed to satisfy the RVOSI scenario requirements as closely as possible.

RVOSI TECHNOLOGY STUDY

Evaluation of LFM/SVR

Evaluation Factor 1. Confidence Level

The LFM/SVR concept development was guided by the requirements of the OSI scenarios; consequently it is theoretically well suited for RVOSI. One of the design considerations was the incorporation of a high degree of spoof resistance. LFM/SVR suffers from existing only on paper; there has not yet been any proof of principle.

Evaluation Factor 3. Intrusiveness

The LFM/SVR system is designed for standoff measurements. Acoustic transmission through the skin of the TLI will inhibit detailed interior viewing; the measured signature is potentially nonintrusive.

Evaluation Factor 4. Operational Impact

The system downtime is estimated to be short - 10 m to 1 h.

Evaluation Factor 5. Inspector's burden

The LFM/SVR system is expected to be highly portable since most of the system is implemented in software which will run on a notebook computer. It is expected to be a rugged and reliable system. Set up, use and break down time are estimated at - 20 m to 1 hr.

Export control constraints

Probably none, similar components used world-wide.

Technological maturity

LFM/SVR is strictly at a conceptual stage. The theory is complete, but no experimentation has yet begun.

Scenario dependence

The LFM/SVR system architecture was developed to satisfy the RVOSI scenario requirements as closely as possible.

ACOUSTICS FOR RVOSI

Low Frequency Mapping/Structural Vibrational Response (LFM/SVR)

LFM/SVR operates in a standoff mode using arrays of acoustic transducers to generate narrow acoustic beams which can be scanned over the surface of the test object. The system can scan on both transmission and reception, or scan only on receive and insonify with a single remote source. The result of the surface scan is a map of the phase and amplitude of the re-radiated acoustic pressure field from the test object. These maps should provide a multi-dimensional signature for the test object. The complex nature of the signature may make it resistant to spoofing.

LFM/SVR can operate with a variety of insonifying waveforms, but typically it will employ sinusoidal pulses. The operating frequency will be chosen to ensure penetration of the acoustic energy into the interior of the test object.

LFM/SVR exists as a well developed concept, but proof-of-principle experiments lay in the future.

RVOSI USING GRAVIMETRY

**Evaluator: Dr. Monte Chawla
SYSTEM PLANNING CORPORATION**

INSPECTION OBJECTIVES

1. **Determine that there are no more than treaty specified number of RVs.**

Yes. Actually, the instrument looks for the total number of RVs but a software interface can be incorporated into the device to address the "no more than" requirement.

2. **Determine the number of RVs.**

Yes.

3. **Detect the presence of nuclear warheads.**

Yes. However, this technology cannot tell whether the material is nuclear. Density of the material can be inferred, and provide a useful clue regarding the material employed in the warhead, but the density evidence will not be conclusive. Reliably matching a signature with a baseline template, will show changes, if any.

4. **Determine the number of nuclear warheads present.**

Yes, the above comments apply.

5. **Distinguish between nuclear and non-nuclear warheads.**

Yes, as long as there are some differences in mass or mass distribution.

6. **Confirm the irreversibility of downloading/bus changes.**

Maybe, as long as there are some differences in mass or mass distribution.

EVALUATION FACTORS

The following comments are offered on an as yet-to-be-built, portable, sensitive gravity gradiometer. A sensitive laboratory prototype exists and appears to work well.

1. CONFIDENCE LEVEL

1.1 Reliability.

Gravimetric techniques can be used to count the number of RVs from a close distance to the missile outerskin. Difficulties may arise if the number of RVs is too large, clustering too tight or standoff distance too great. RVOSI from outside a canister will be difficult. Counting fidelity can be improved by employing an instrument that measures higher-order spatial derivatives of the gravity potential. Instruments for measuring derivatives greater than second-order do not exist at present. Gravity gradiometers that measure second derivatives may be optimal instruments for RVOSI. A high signal-to-noise ratio of the laboratory prototype, translates to a high reliability of the measurements for most scenarios.

1.2 Spoofing immunity.

Gravimetric measurements are not easy to spoof because the mass cannot be hidden. Any attempt to rearrange the mass for masking the gradiometric signature will usually require redesigning the RV, a step which appears to be highly improbable. External spoofing can be easily foiled by repeating the measurements at another standoff distance.

3. INTRUSIVENESS

3.1 Information gained beyond what is required for inspection.

The mass, mass distribution, and the RV placement can be deduced from the gravimetric signatures. However, this is not considered intrusive under the current treaty rules.

3.2 Can potentially intrusive information be masked and inspection still be completed.

The already low-level of intrusiveness can be further reduced by converting the analog signature to a binary output. A binary 1 will correspond to a gravitational peak produced by an RV and a binary 0 will correspond to the empty space in between the RVs. Another level of reduction in the intrusiveness can be achieved by a simple "yes" or "no" type answer to an appropriate query. Inspecting parties, however, may need to retain the "raw data" for subsequently justifying the challenge. This may be unacceptable to the inspected party.

4. OPERATIONAL IMPACT

4.1 System downtime.

The system downtime may comprise obtaining access to the missile nose, initializing and checking-out the instrument, setting up a rotating table, carrying the gravity gradiometer, making the measurements, and analyzing the results. The estimated time for measurements will be 5 manhours. The signature collection itself is not expected to take more than one hour; each scan taking only a few minutes. This time estimate excludes that required to raise the missile for the most favorable instrument positioning. Significant time savings can be obtained if the preparatory instrument work can be done in parallel and/or in advance.

4.2 Operational requirements.

A gravity gradiometer needs to be in close proximity to the missile skin. High precision placement of the instrument may not be necessary for RVOSI. User-friendliness of the instrument is expected.

5. INSPECTOR'S BURDEN

The following information is provided on two of the currently available gravity gradiometers. The University of Maryland Gravity Gradiometer (SGG) is probably the most sensitive instrument, but it exists in a laboratory prototype stage. Bell's fielded instrument, Gravity Gradiometer Instrument (GGI), may not have the sufficient sensitivity.

	<u>UM SGG</u> <u>(Prototype)</u>	<u>Bell GGI</u> <u>(Fielded)</u>
1. Sensor Weight (lb)	600	35
2. Sensor Dimension (in)	18.5 x 7.5	8.5 x 9.4
3. Electronics	2 cabinets	2 cabinets
4. Portability	None	None
5. Ease of Use	High	High
6. Measurement Time (Guess)	1 hour	1 hour
7. How long of use	1 week*	MTBF
8. Safety	Cryogenics	Rotating machinery
9. Power Requirement	30 W	?
10. Ruggedness	No	Yes
11. EM Interference	None	None

* Weekly cryogenic fluid replenishment.

6. OTHER FACTORS

6.1 Export control policy at the present time.

University of Maryland's SGG employs niobium material for proof masses, SQUID for detectors, and a PC for data collection. All of these are considered "low-tech" and available overseas. There was, however, an incident in which a Soviet visit request to the gradiometer lab was denied by the State Department. No export hurdles are expected if a "release from export-control" application were to be made.

Bell's GGI employs state-of-art accelerometers and signal processing algorithms. An export license has been applied for about six months back. Bell is still awaiting the outcome of its request but does not anticipate any problems.

6.2 Technical maturity.

Both the UM's SGG and Bell's GGI instruments have benefitted from continuous research over at least a decade. Also, there is abundant published literature describing various aspects of the instrument functionality. However, the SGG is a laboratory research tool and currently lacks portability and ruggedness that will be designed into a device suited for arms-control work. Bell's fielded GGI may lack the required sensitivity. However, Bell's modified instrument addresses this deficiency.

6.3 Scenario dependance.

Wire-line based gradiometer systems should be developed for lowering into a silo if in-situ RVOSI is permitted. Missiles on flatbeds and inside canisters may pose difficulties due to space and accessibility constraints.

APPENDIX B
GAMMA-RAY IMAGING SYSTEM REVIEW

B-1. RVOSI Study Team Technical Review of GRIS

Based on the Reentry Vehicle On-Site Inspection (RVOSI) Technology Study Group's decision-tree process, the Gamma-Ray Imaging System (GRIS), developed under the Department of Energy Office of Arms Control and Nonproliferation Radiation Detection Program by Lawrence Livermore National Laboratory (LLNL), has a high potential for becoming a useful on-site inspection tool for counting nuclear warheads on intercontinental ballistic missiles (ICBMs) while they remain in their launchers. As an additional task to the RVOSI technology study, a GRIS review team was formed by some members of the RVOSI technology study team:

Mary Abe, team leader	Army Research Laboratory
Ahmed Abou-Auf	Army Research Laboratory
Dr. Don Eccleshall	Army Research Laboratory
Dr. M. William Johnson	Los Alamos National Laboratory
John McNeilly	SAIC/Center for Verification Technology
Manuel Sanches	System Planning Corporation

B-2. Background Discussions

Our team visited LLNL on 16 and 17 November 1992. James "Buddy" Swingle provided the team with programmatic information, and Klaus Ziock gave an extensive technical briefing. Since the members of this GRIS review team came from diverse backgrounds, a comprehensive discussion of the GRIS program and design philosophy was essential to a successful review. We asked the LLNL staff to discuss the following questions.

- Why was this particular system (hardware and software) chosen?
- Were other alternatives considered and, if so, why were they abandoned?
- What types of modeling have been used to augment and guide the experimental program?
- What was the overall experimental program and what specific tests have been completed?
- What do the developers (LLNL) consider are remaining technical issues?

We learned that the LLNL staff chose the GRIS instrument for development simply because it was expedient, not because it was specifically designed for the RVOSI task. The instrument is an adaptation of a coded-aperture telescope developed for astrophysics applications. GRIS consists of two parts: a camera module and data-collection and analysis electronics connected to the imaging module via an umbilical. The camera module also has two parts: a shadow mask, known as a uniformly redundant array (URA), and a position-sensitive detector. The data-collection and analysis electronics are based on standard systems. Little work has been done to optimize size, weight, or operator interfaces for the data-collection system at this time. A complete description of the GRIS hardware and operating principles can be found in Ziock et al.¹

¹Ziock, K. P., C. J. Hailey, T. B. Gosnell, J. H. Lupton, and F. A. Harrison, *A Gamma-Ray Imager for Arms Control*, conference record of the 1991 IEEE Nuclear Science Symposium and Medical Imaging Conference, Santa Fe, NM, p 1228 (5-9 November 1991).

Prior to the 1989 F. E. Warren Peacekeeper demonstration, little calculational work had been conducted to characterize the GRIS instrument for RVOSI. Limited laboratory testing and a trial at the Los Alamos National Laboratory Simulation Facility, along with the experience base of using a GRIS-like instrument for astrophysics application, had indicated that the instrument should be able to count warheads in the Peacekeeper configuration. The quality of the image generated at this first Peacekeeper demonstration fell far short of expectations.¹ As a result of this trial, several modifications to the GRIS camera and operating procedure were made. These modifications included improved shielding to reduce background due to scattered radiation, a 10-percent reduction of the basic mask pattern to eliminate use of the most spatially non-linear detector regions, an improved linearization algorithm to correct for detector non-linearities, and two-part imaging with half of the data collected with a mask and half of the data collected with an anti-mask. The resulting instrument tested against the Peacekeeper in 1992 showed markedly better results, although some questions remained regarding data interpretation.²

The GRIS technology development program is scheduled for completion in FY93. The major efforts planned for the program are the refinement of data processing from the 1992 F. E. Warren test and the characterization of a performance envelope for the existing instrument. Plans for envelope characterization will focus on looking at the effects of materials between the source to be imaged and the GRIS instrument, since this is the hypothesized cause of unresolved difficulties encountered in the F. E. Warren experiments. Data processing development will focus on improved statistical algorithms and related source models. At the time of the GRIS review, a chi-squared data fit had been attempted to identify warhead positions from the 1992 Peacekeeper demonstration. Although this method could be manipulated to show interesting features in the data, the LLNL and RVOSI review teams agreed that other statistical methods should be explored. Our review team was generally supportive of the LLNL FY93 planned program. Specific suggestions and concerns will be discussed in section B-3.

We also posed numerous detailed questions to the LLNL personnel responsible for GRIS development. In many instances, especially regarding data interpretation, the GRIS system was less mature than we had envisioned; therefore, some of the questions were treated less rigorously than we had hoped.

B-3. Review Issues

Our study team was tasked by DNA to specifically address five issues related to GRIS development and maturity. The issues and a discussion of our findings regarding each issue are contained in this section.

Issue 1: The robustness of the data processing algorithms for converting raw data into a quantitative assessment of the number of sources present, realizing that RVOSI scenarios may not include revelation of the actual image.

¹Ziock, K. P., C. J. Hailey, T. B. Gosnell, J. H. Lupton, and F. A. Harrison, *A Gamma-Ray Imager for Arms Control*, conference record of the 1991 IEEE Nuclear Science Symposium and Medical Imaging Conference, Santa Fe, NM, p 1228 (5-9 November 1991).

²Gosnell, T. B., J. D. Cole, B. D. Geelhood, S. D. Miller, H. L. Scott, and K. P. Ziock., *Warhead-Counting Demonstration for RVOSI by Department of Energy Laboratories*, Lawrence Livermore National Laboratory, JEP-001 (October 1992).

The focus of the GRIS development program up to the point of this review had been to develop an image so that sources could be visually counted. The uncertainties in accomplishing this task are linked to incomplete characterization of the camera system, which is more fully discussed with issue 5. As characterization of the instrument progresses, the team anticipates that modifications to the data handling software will be incorporated. Of special importance in the early stages are algorithms that will correct for shielding and scattering from intervening materials. As mentioned previously, this is the focus of camera characterization studies planned for FY93. In connection with this, a clear explanation of the steps required for accurate instrument calibration is important if the instrument is to be transferred into an advanced development program.

Issue 2: The utility of the current GRIS hardware, especially the camera, for adaptation to potential inspection scenarios.

The team has identified a number of advanced development issues that must be applied to any system, including GRIS, should DNA choose to pursue advanced development. These issues are included in the main body of the report. Hardware optimization and software user interfaces for the data-collection and analysis electronics are the most obvious focus for GRIS advanced development, since little optimization has been attempted for these systems. Any modifications that will reduce weight, volume, or power consumption of these components are desirable for the RVOSI application. As pointed out by the LLNL group, the electronics associated with GRIS clearly can be designed to better fit all of these requirements. The GRIS camera can be fine tuned for specific configurations. Some optimization of weight, volume, or power consumption may be possible. A redesign of the URA and repackaging for more ruggedness and easier use can also be easily introduced when the camera's performance envelope is better understood. With a systematic envelope characterization, as proposed in the discussion of issue 5, the GRIS project provides the information that DNA would require to begin an advanced development project.

Issue 3: The ability of the current camera design to filter or suppress the noise resulting from scattered photons.

The team and DNA were very concerned about this issue after viewing the results of the first F. E. Warren demonstration. The team accepts that the mask/anti-mask process, along with added shielding used at the second F. E. Warren demonstration, has adequately addressed the scattering problems encountered in the first F. E. Warren demonstration. However, any other ideas for addressing this issue and reducing counting time would be valuable if the project moves into advanced development.

Issue 4: The choice and implementation of the image correlation statistics used to determine the confidence in the quantitative assessment used of the source population.

Algorithms for automatic pattern recognition, encoding or masking of the collected raw data, to reduce the possibility of intrusion and optimize the associated data processing software, would be major software design efforts for a fieldable system. The chi-squared approach, considered at the time of this review, is inadequate for a final system. LLNL expects to pursue this effort through 1993; their progress will be invaluable to an advanced development program.

Issue 5: The experimental details of the measurements and data collected to date from various laboratory and field tests, and plans for laboratory simulations aimed at assessing robustness of data interpretation methods in the presence of intervening materials.

The team strongly endorses LLNL's plan to characterize the operating envelope of the current GRIS hardware. The team is particularly hopeful that these studies will identify the critical performance parameters of the camera system so they can be optimized as design characteristics for RVOSI. At the time of the team's review, a number of questions remained regarding the F. E. W. test results and resolution of the GRIS image. The team has identified the following areas for further exploration:

- performance characteristics as a function of distance from the source to the sensor
- the effect of partial shadowing of the URA mask by intervening material in, for example, a shroud ejector motor
- the effect of non-uniform illumination of the mask due to extended sources lying with their surfaces nearly at right angles to the direction of the mask
- the effect of x-rays from off-axis source locations for which the x-rays enter the mask non-normally and give rise to a spatial modulation of the encoding by the mask or to a spatial frequency-dependent imaging
- the effect of intervening and surrounding materials that cause scattering and increased background.

The team perceived a current lack of design parameter studies, which will make optimization of the instrument difficult, if not impossible, for any future developer.

A research area that our team discussed while in Livermore, and which continues to be a primary concern, is the lack of a radiation transport modeling study in conjunction with GRIS development. As we have discussed our general recommendations with DNA, lack of modeling studies for all proposed technologies has come to dominate our concerns for future RVOSI research. It is our view that modeling efforts that could determine tradeoffs between neutron and gamma-ray detection methods, assess Russian configurations, and support spoofing scenarios will be valuable tools when DNA develops its RVOSI technology investment strategy. Monte Carlo simulations of radiation transport in representative missile systems are our highest priority recommendation for immediate DNA investment.

B-4. Conclusion

GRIS appears to be a viable candidate for advanced development. When the camera characterization is successfully completed, hardware and software optimization can begin. Uncertainties about the camera's performance prevent us from firmly endorsing this technology for advanced development at this time.

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